

FORM PTO-1390 (Modified)
(REV 11-2000)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES

164748 (8830-26)

DESIGNATED/ELECTED OFFICE (DO/EO/US)

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

CONCERNING A FILING UNDER 35 U.S.C. 371

Not yet assigned 10/070768

INTERNATIONAL APPLICATION NO.
PCT/GB00/03431INTERNATIONAL FILING DATE
07 September 2000PRIORITY DATE CLAIMED
07 September 1999

TITLE OF INVENTION

Radar Apparatus for Imaging and/or Spectrometric Analysis and Methods of Performing Imaging and/or Spectrometric Analysis of a Substance, Dimensional Measurement, Identification and Precision Radar Mapping

APPLICANT(S) FOR DO/EO/US

George Colin STOVE

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
 - a. ☒ is attached hereto (required only if not communicated by the International Bureau).
 - b. ☐ has been communicated by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
 - a. ☐ is attached hereto.
 - b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
 - a. ☐ are attached hereto (required only if not communicated by the International Bureau).
 - b. ☐ have been communicated by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☐ have not been made and will not be made.
8. ☐ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

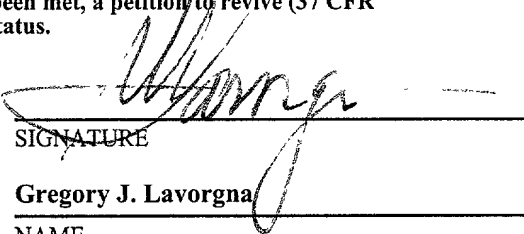
13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☐ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☐ Other items or information:

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 1.492(a)(1)-(5)) Not yet assigned 10,670,768	INTERNATIONAL APPLICATION NO. PCT/GB00/03431	ATTORNEY'S DOCKET NUMBER 164748 (8830-26)
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24. The following fees are submitted: BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) : <input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO \$1040.00 <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO \$890.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$740.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) \$710.00 <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) \$100.00 ENTER APPROPRIATE BASIC FEE AMOUNT =				CALCULATIONS PTO USE ONLY	
				\$890.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492 (e)). <input checked="" type="checkbox"/> 20 <input type="checkbox"/> 30				\$130.00	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	62 - 20 =	42	x \$18.00	\$756.00	
Independent claims	3 - 3 =	0	x \$84.00	\$0.00	
Multiple Dependent Claims (check if applicable)			<input type="checkbox"/>	\$0.00	
TOTAL OF ABOVE CALCULATIONS =				\$1,776.00	
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				\$0.00	
SUBTOTAL =				\$1,776.00	
Processing fee of \$130.00 for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492 (f)). <input type="checkbox"/> 20 <input type="checkbox"/> 30 +				\$0.00	
TOTAL NATIONAL FEE =				\$1,776.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable).				<input type="checkbox"/>	\$0.00
TOTAL FEES ENCLOSED =				\$1,776.00	
				Amount to be refunded	\$
				charged	\$

- a. ☒ A check in the amount of **\$1,776.00** to cover the above fees is enclosed.
- b. ☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees. A duplicate copy of this sheet is enclosed.
- c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **50-0573** A duplicate copy of this sheet is enclosed.
- d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:	
Gregory J. Lavorgna, Esq. Drinker Biddle & Reath, LLP One Logan Square 18th and Cherry Streets Philadelphia, PA 19103-6996 Phone: (215) 988-3309 Fax: (215) 988-2757	 SIGNATURE Gregory J. Lavorgna NAME 30,469 REGISTRATION NUMBER March 7, 2002 DATE

10/070768

JC10 Rec'd PCT/PTO 07 MAR 2002

PATENT

Docket No.: 164748
(8830-26)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re: Patent application of :
George Colin STOVE :
Serial Not yet assigned : Group Art Unit:
: Not yet known
International Serial No: PCT/GB00/03431 :
International Filing Date: 07 September 2000 : Examiner:
: Not yet known
For: Radar Apparatus for Imaging and/or :
Spectrometric Analysis and Methods of :
Performing Imaging and/or Spectrometric :
Analysis of a Substance, Dimensional :
Measurement, Identification and Precision :
Radar Mapping :

PRELIMINARY AMENDMENT

Commissioner for Patents

Washington, D.C. 20231

Sir:

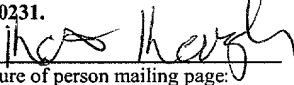
Kindly amend the above-identified application, without prejudice, in advance of calculating the filing fee. A mark-up of the amended claims is contained in Appendix A hereto.

CERTIFICATE OF MAILING
UNDER 37 C.F.R. 1.10

EXPRESS MAIL Mailing Label Number: EL 813788610 US

Date of Deposit: _____

I hereby certify that this correspondence, along with any paper referred to as being attached or enclosed, and/or fee, is being deposited with the United States Postal Service, "EXPRESS MAIL-POST OFFICE TO ADDRESSEE" service under 37 C.F.R. 1.10, on the date indicated above, and addressed to: Commissioner for Patents, Washington, D.C. 20231.


Signature of person mailing page:

Katie Keogh

Type or print name of person

In the Claims

Rewrite claims 4, 8-10, 12, 16-18, 21-24, 27, 30-53, and 58-62 as follows:

4. A radar antenna assembly as claimed in Claim 2, wherein said focussing means includes at least one dielectric lens element located at said second end.
8. A radar antenna assembly as claimed in Claim 1, wherein said tubular casing has an inner diameter D_T of which is an integer multiple of the diameter D_A of said at least one antenna element.
9. (A radar antenna assembly as claimed in Claim 1, wherein said tubular casing has an interior length L_T which is an integer multiple of the length L_A of said at least one antenna element.
10. A radar antenna assembly as claimed in Claim 1, wherein an interior surface of said tubular casing comprises an antenna cathode and said elongate antenna element comprises an antenna anode.
12. A radar antenna assembly as claimed in Claim 1, including at least two elongate antenna elements, at least one of which comprises an antenna cathode and at least one of which comprises an antenna anode.
16. A radar antenna assembly as claimed in Claim 1, wherein said dielectric material is a liquid.
17. A radar antenna assembly as claimed in Claim 1, wherein said dielectric material is a solid.
18. A radar antenna assembly as claimed in Claim 1, wherein said dielectric material is a powdered solid packed into the interior of said tubular casing.
21. A radar antenna apparatus as claimed in Claim 19, wherein the base of said pyramidal structure is closed by a generally planar base wall, said chamber comprising the interior volume of said pyramidal structure.
22. A radar antenna assembly as claimed in Claim 19, wherein said chamber comprises a closed volume communicating with the open base of said pyramidal structure.
23. A radar system comprising pulsed signal generating means, transmitter antenna means, receiver antenna means, control means for controlling the operation of said pulsed signal generating

means, analog-digital converter means for digitising signals received by said receiver antenna means, and data storage means for storing said digitised signals, wherein said transmitter antenna means and receiver antenna means comprise at least one radar antenna including one of:

(i) a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;

a radar-reflective reflector closing said first end;

an aperture disposed at said second end;

at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and

dielectric material substantially filling the interior volume of said tubular casing; or

(ii) a closed chamber adapted to contain a sample of material, said chamber including four substantially triangular side walls together defining an open-based pyramidal structure, said assembly including transmitter antenna elements disposed on interior surfaces of a first opposed pair of said triangular side walls and receiver antenna elements disposed on interior surfaces of a second opposed pair of said triangular side walls.

24. A radar system as claimed in Claim 23, wherein said transmitter antenna means comprises at least one transmitter radar antenna assembly and said receiver antenna means comprises at least one receiver radar antenna said transmitter antenna assembly and said receiver transmitter assembly each comprising:

a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;

a radar-reflective reflector closing said first end;

an aperture disposed at said second end;

at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and dielectric material substantially filling the interior volume of said tubular casing.

27. A radar system as claimed in Claim 24, wherein said transmitter and receiver antenna assemblies are connected to a closed sample chamber adapted to enclose a subject.

30. A radar system as claimed in Claim 28, wherein said system is adapted to be portable.

31. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a land vehicle.

32. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a water-borne vessel.
33. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a submersible vehicle.
34. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by an airborne vehicle.
35. A radar system as claimed in Claim 28, wherein said system is adapted to be carried by a space vehicle.
36. A radar system as claimed in Claim 28, wherein the position of said transmitter antenna assembly is fixed relative to said receiver antenna assembly.
37. A radar system as claimed in Claim 28, wherein at least one of said transmitter antenna assembly and said second antenna assembly is adapted to be movable relative to a subject.
38. A radar system as claimed in Claim 28 in which one of said transmitter and receiver antenna assemblies is adapted to be movable relative to the other.
39. A radar system as claimed in Claim 28, including a plurality of transmitter antenna assemblies.
40. A radar system as claimed in Claim 28, including a plurality of receiver antenna assemblies.
41. A radar system as claimed in Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 100 kHz.
42. A radar system as claimed in Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 0.01 to 0.1 nanoseconds.
43. A radar system as claimed in Claim 28, for use with close range subjects, adapted to capture data in a time range of 2 to 25 nanoseconds.

44. A radar system as claimed in Claim 28, for use with close range subjects, adapted to transmit pulses with a minimum frequency in the range 100 to 1000 MHz and with a maximum frequency in the range 1000 to 10000 MHz.
45. A radar system as claimed in Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 25 to 100 kHz.
46. A radar system as claimed in Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 1 to 10 nanoseconds.
47. A radar system as claimed in Claim 28, for use with close to medium range subjects, adapted to capture data in a time range of 2000 to 10000 nanoseconds.
48. A radar system as claimed in Claim 28, for use with close to medium range subjects, adapted to transmit pulses with a minimum frequency in the range 12.5 to 125 MHz and with a maximum frequency in the range 200 to 2000 MHz.
49. A radar system as claimed in Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 3.125 to 50 kHz.
50. A radar system as claimed in Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 10 to 25 nanoseconds.
51. A radar system as claimed in Claim 28, for use with long range subjects, adapted to capture data in a time range of 20000 to 250000 nanoseconds.
52. A radar system as claimed in Claim 28, for use with long range subjects, adapted to transmit pulses with a minimum frequency in the range 1 to 12.5 MHz and with a maximum frequency in the range 12.5 to 200 MHz.
53. A radar system as claimed in Claim 28, further including data processing means for processing said digitised signals.

58. A method as claimed in Claim 55, wherein said step of analysing said energy-frequency spectrum comprises frequency classification using energy bins.
59. A method as claimed in Claim 55, wherein said step of analysing said energy-frequency spectrum comprises energy classification using frequency bins.
60. A method of identifying an unknown subject comprising the steps of:
obtaining an energy-frequency signature of said subject using the method of Claim 55; and
comparing said energy-frequency signature of the unknown subject to a database of energy-frequency signatures of known subjects previously obtained using the method of Claim 55.
61. A method as claimed in Claim 55, implemented using a radar system as claimed in Claim 53.
62. A radar system as claimed in Claim 53, wherein said data processing means is adapted to perform the method of Claim 55.

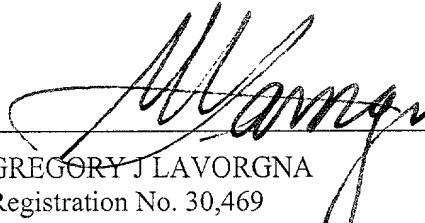
Remarks

Claims 1 to 24 are pending in the application. The claims have been amended to eliminate multiple claim dependencies and more closely conform them to United States practice. The specification was not amended in the international phase.

An early action on the merits is requested.

Respectfully Submitted,

George Colin STOVE



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APPENDIX A: Mark-up of amended claims

4. (Amended) A radar antenna assembly as claimed in Claim 2 [or Claim 3], wherein said focussing means includes at least one dielectric lens element located at said second end.
8. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said tubular casing has an inner diameter D_T of which is an integer multiple of the diameter D_A of said at least one antenna element.
9. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said tubular casing has an interior length L_T which is an integer multiple of the length L_A of said at least one antenna element.
10. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein an interior surface of said tubular casing comprises an antenna cathode and said elongate antenna element comprises an antenna anode.
12. (Amended) A radar antenna assembly as claimed in [any one of Claims 1 to 9] Claim 1, including at least two [of said] elongate antenna elements, at least one of which comprises an antenna cathode and at least one of which comprises an antenna anode.
16. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said dielectric material is a liquid.
17. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said dielectric material is a solid.
18. (Amended) A radar antenna assembly as claimed in [any preceding Claim] Claim 1, wherein said dielectric material is a powdered solid packed into the interior of said tubular casing.
21. (Amended) A radar antenna apparatus as claimed in Claim 19 [or Claim 20], wherein the base of said pyramidal structure is closed by a generally planar base wall, said chamber comprising the interior volume of said pyramidal structure.
22. (Amended) A radar antenna assembly as claimed in Claim 19 [or Claim 20], wherein said chamber comprises a closed volume communicating with the open base of said pyramidal structure.

23. (Amended) A radar system comprising pulsed signal generating means, transmitter antenna means, receiver antenna means, control means for controlling the operation of said pulsed signal generating means, analog-digital converter means for digitising signals received by said receiver antenna means, and data storage means for storing said digitised signals, wherein said transmitter antenna means and receiver antenna means comprise at least one radar antenna assembly [as claimed in any one of Claims 1 to 22] including one of:

(i) a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;

a radar-reflective reflector closing said first end;

an aperture disposed at said second end;

at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and

dielectric material substantially filling the interior volume of said tubular casing; or

(ii) a closed chamber adapted to contain a sample of material, said chamber including four substantially triangular side walls together defining an open-based pyramidal structure, said assembly including transmitter antenna elements disposed on interior surfaces of a first opposed pair of said triangular side walls and receiver antenna elements disposed on interior surfaces of a second opposed pair of said triangular side walls.

24. (Amended) A radar system as claimed in Claim 23, wherein said transmitter antenna means comprises at least one transmitter radar antenna assembly [as claimed in any one of Claims 1 to 18,] and said receiver antenna means comprises at least one receiver radar antenna assembly [as claimed in any one of Claims 1 to 19], said transmitter antenna assembly and said receiver transmitter assembly each comprising:

a tubular casing having a radar-reflective inner surface and having a first end, a second end and a longitudinal axis;

a radar-reflective reflector closing said first end;

an aperture disposed at said second end;

at least one elongate antenna element extending substantially parallel to said longitudinal axis from said reflector towards said second end; and dielectric material substantially filling the interior volume of said tubular casing.

27. (Amended) A radar system as claimed in [any one of Claims 24 to 26] Claim 24, wherein said transmitter and receiver antenna assemblies are connected to a closed sample chamber adapted to enclose a subject.

30. (Amended) A radar system as claimed in Claim 28 [or 29], wherein said system is adapted to be portable.

31. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by a land vehicle.

32. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by a water-borne vessel.

33. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by a submersible vehicle.

34. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein said system is adapted to be carried by an airborne vehicle.

35. (Amended) A radar system as claimed in Claim 28 [or 29], wherein said system is adapted to be carried by a space vehicle.

36. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein the position of said transmitter antenna assembly is fixed relative to said receiver antenna assembly.

37. (Amended) A radar system as claimed in Claim 28 [or Claim 29], wherein at least one of said transmitter antenna assembly and said second antenna assembly is adapted to be movable relative to a subject.

38. (Amended) A radar system as claimed in Claim 28 [or Claim 29] in which one of said transmitter and receiver antenna assemblies is adapted to be movable relative to the other.

39. (Amended) A radar system as claimed in [any one of Claims 28 to 38] Claim 28, including a plurality of transmitter antenna assemblies.

40. (Amended) A radar system as claimed in [any one of Claims 28 to 39] Claim 28, including a plurality of receiver antenna assemblies.

41. (Amended) A radar system as claimed in [any one of Claims 28 to 40] Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 100 kHz.

42. (Amended) A radar system as claimed in [any one of Claims 28 to 41] Claim 28, for use with close range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 0.01 to 0.1 nanoseconds.

43. (Amended) A radar system as claimed in [any one of Claims 28 to 42] Claim 28, for use with close range subjects, adapted to capture data in a time range of 2 to 25 nanoseconds.

44. (Amended) A radar system as claimed in [any one of Claims 28 to 43] Claim 28, for use with close range subjects, adapted to transmit pulses with a minimum frequency in the range 100 to 1000 MHz and with a maximum frequency in the range 1000 to 10000 MHz.

45. (Amended) A radar system as claimed in [any one of Claims 28 to 40] Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 25 to 100 kHz.

46. (Amended) A radar system as claimed in [any one of Claims 28 to 40 or 45] Claim 28, for use with close to medium range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 1 to 10 nanoseconds.

47. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 45 or 46] Claim 28, for use with close to medium range subjects, adapted to capture data in a time range of 2000 to 10000 nanoseconds.

48. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 45 to 47] Claim 28, for use with close to medium range subjects, adapted to transmit pulses with a minimum frequency in the range 12.5 to 125 MHz and with a maximum frequency in the range 200 to 2000 MHz.

49. (Amended) A radar system as claimed in [any one of Claims 28 to 40] Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse repetition frequency of the order of 3.125 to 50 kHz.

50. (Amended) A radar system as claimed in [any one of Claims 28 to 40 or 49] Claim 28, for use with long range subjects, in which said control means is adapted to control said pulsed signal generating means so as to generate pulses with a pulse width in the range 10 to 25 nanoseconds.
51. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 49 or 50] Claim 28, for use with long range subjects, adapted to capture data in a time range of 20000 to 250000 nanoseconds.
52. (Amended) A radar system as claimed in [any one of Claims 28 to 40, or 49 to 51] Claim 28, for use with long range subjects, adapted to transmit pulses with a minimum frequency in the range 1 to 12.5 MHz and with a maximum frequency in the range 12.5 to 200 MHz.
53. (Amended) A radar system as claimed in [any one of Claims 23 to 52] Claim 28, further including data processing means for processing said digitised signals.
58. (Amended) A method as claimed in [any one of Claims 55 to 57] Claim 55, wherein said step of analysing said energy-frequency spectrum comprises frequency classification using energy bins.
59. (Amended) A method as claimed in [any one of Claims 55 to 57] Claim 55, wherein said step of analysing said energy-frequency spectrum comprises energy classification using frequency bins.
60. (Amended) A method of identifying an unknown subject comprising the steps of:
obtaining an energy-frequency signature of said subject using the method of [any one of Claims 55 to 59] Claim 55; and
comparing said energy-frequency signature of the unknown subject to a database of energy-frequency signatures of known subjects previously obtained using the method of [any one of Claims 55 to 59] Claim 55.
61. (Amended) A method as claimed in [any one of Claims 55 to 60] Claim 55, implemented using a radar system as claimed in Claim 53 [or 54].
62. (Amended) A radar system as claimed in Claim 53 [or 54], wherein said data processing means is adapted to perform the method of [any of Claims 55 to 60] Claim 55.

21/PRTS

1 Radar Apparatus for Imaging and/or Spectrometric
2 Analysis and Methods of Performing Imaging and/or
3 Spectrometric Analysis of a Substance for Dimensional
4 Measurement, Identification and Precision Radar Mapping

5
6 This invention relates to radar apparatus and methods
7 of use thereof for imaging and/or spectrometric
8 analysis. In particular, it relates to pulsed radar
9 apparatus for magnifying, imaging, scale measuring,
10 identifying and/or typecasting the composition of a
11 substance by radargrammetric imaging and/or
12 spectrometric analysis. The invention further relates
13 to the use of the radar apparatus to locate and/or
14 distinguish a substance from other substances. The
15 invention may additionally be used to image a
16 substance/feature and to monitor the movement of an
17 imaged substance/feature. Such moving
18 substances/features include but are not limited to the
19 flow of blood and other substances moving within a
20 human or animal body, and substances/features in a

1 subterranean environment, such as the movement of
2 water, oil, gas and/or contaminants below the ground
3 surface, below standing or flowing water bodies, or
4 below sea level and the seabed.

5
6 Radar systems and methods in accordance with the
7 invention can be adapted for a variety of applications
8 at a wide range of scales and distances. These vary
9 from large scale, long range applications such as
10 airborne, seaborne and ground based geophysical
11 imaging/analysis of the Earth's surfaces and sub-
12 surfaces, for example precision mapping and
13 classification of sea-bed materials and also soil,
14 sediment and rock type mapping and classification to
15 medium scale, medium range applications such as "ground
16 level" (on land or water bodies) imaging/analysis such
17 as sea-bed and ground penetrating applications at
18 relatively shallow depths, to the small scale such as
19 material typecasting applications and small scale
20 (including microscopic) imaging/analysis, including
21 biological and medical imaging and diagnostic
22 applications. The invention might also be extended to
23 very long range/large scale space based imaging and
24 analysis applications, such as orbital surveying of
25 planets and astronomical applications.

26
27 The scale (i.e. range and resolution) the radar
28 apparatus operates on is determined to a greater or
29 lesser extent by the geometry of transmitting and
30 receiving antenna apparatus employed in systems
31 according to the invention. It is also affected by the

1 properties of dielectric materials employed in such
2 apparatus.

3
4 Certain aspects of the invention concern certain
5 conditions being achieved during the set up of the
6 apparatus so as to obtain "standing wave oscillations"
7 in sample chambers and/or in antenna assemblies. In
8 this respect it is important to selectively control the
9 group velocity of the radiation as it is emitted or
10 "launched" by the transmitter into the surrounding
11 medium. In particular, for deep scanning it is
12 important for the launch speed of the wave to be
13 sufficiently slow to ensure that the wave can be
14 accurately registered at a precise "zero time" location
15 by the receiver after the pulse has been transmitted.
16 The zero time position is the start position for range
17 measurements and must be identified on the received
18 radar signal to determine the true range represented by
19 the received signal.

20
21 Setting up the standing wave oscillations for different
22 time ranges or time windows such as, for example, 25
23 ns, 50 ns, 100 ns, 1000 ns or 20,000 ns, would all
24 involve different zero time locations. Different time
25 ranges are required to enable the different depth
26 ranges required for certain precision mapping
27 applications to be obtained. Accurate location of the
28 zero time point is important and can be a difficult
29 procedure: inaccurately pinpointing the zero time
30 introduces a systematic shift in the location of all
31 radar measurements. Certain embodiments of the
32 invention register the zero time location prior to the

1 received radar signal being converted from analogue to
2 digital form. This enables a more accurate zero time to
3 be located than can be obtained by using conventional
4 techniques. Preferred embodiments of the invention
5 locate the optimum position for time zero, for mapping
6 or "staring" operations, by digital means using
7 mathematical logic.

8

9 A blind spot of the order of 1 meter in close proximity
10 (the near range) to the radar apparatus could generate
11 an equivalent position shift in the radar map of
12 features detected. Such near range blind spots can
13 thus be highly undesirable. By accurately locating the
14 position of the zero time point in the received signal
15 radar, such blind spots can be mitigated or obviated.

16

17 Although ground penetrating radars (GPRs) are already
18 known as non-destructive testing tools their analytical
19 capabilities have been restricted and imaging is often
20 crude using conventional devices. Conventional radar
21 systems which use electromagnetic waves to investigate
22 the internal structure of non-conducting substances
23 within the ground provide relatively low resolution.
24 Furthermore, they are often unwieldy devices and
25 require skilled technical operators.

26

27 The apparatus, systems and methods of the invention may
28 be used for a variety of purposes, particularly but not
29 exclusively three basic types of application. The
30 first of these relates to identifying or "typecasting"
31 unknown materials using their spectral characteristics;
32 i.e. using energy-frequency characteristics, and may be

1 referred to generally as "typecasting" operations. The
2 second relates to use of the equipment in the field or
3 laboratory, for detecting and/or mapping and/or
4 measuring and/or analysing structures or materials, for
5 example; these may be referred to generally as
6 "surveying" operations. The third relates to use of
7 the apparatus to locate materials previously typecast,
8 and to search for them in the field or laboratory and
9 may be referred generally to as the "searching"
10 operations. The various types of operation are
11 supported by suitable software which enables the field
12 or laboratory imaging and analysis processes to be
13 performed in near real time.

14
15 The inventor believes that a key feature of the
16 invention is the set up of resonant conditions in the
17 transmitter/receiver apparatus. This is affected by
18 the dimensions and/or the geometry of a transmitter
19 cavity and a receiver cavity which substantially
20 surround respective transmitting and receiving
21 antennae. In particular, the relative proportions of
22 the lengths and widths of the antenna element(s) to the
23 lengths and widths of the surrounding cavities are
24 important. Ideally the internal diameter of an antenna
25 cavity, whose walls may form the cathode element of an
26 antenna in certain embodiments, is an integer multiple
27 of the diameter of the internal antenna anode element,
28 and similarly, the internal length of the is ideally an
29 integer multiple of the length of the antenna anode
30 element. The resonant conditions may be further
31 affected by at least partially cladding the antennae
32 element(s) with a suitable dielectric cladding

1 material. Furthermore, the selection of a suitable
2 dielectric material to clad the transmitting and
3 receiving antenna elements is believed to further
4 assist in the near range focusing and in more
5 accurately pin-pointing the zero time position, the
6 start position for range measurements.

7
8 The invention seeks to provide radar apparatus having a
9 transmitter which is capable of emitting a beam of
10 electromagnetic radiation into or towards a substance
11 and a receiver which is capable of receiving
12 electromagnetic radiation which has passed through or
13 been reflected from the substance. The radiation is
14 preferably a pulsed radar type signal. The radar
15 signal may be provided by a conventional pulsed radar
16 unit. The radar apparatus includes a suitable tuning
17 means which is capable of controlling the spectral
18 characteristics, for example the power and bandwidth,
19 of the emitted radar signal. The spectral
20 characteristics of the emitted radar signal are
21 controlled so that by suitably irradiating a substance,
22 a frequency response dependent on the composition of
23 the substance can be detected by the receiver.

24
25 Suitable substances whose composition and/or structure
26 can be detected by the apparatus include solids,
27 liquids and composite substances such as powders, soil
28 or sediment. Liquid substances may be admixtures
29 and/or emulsions (e.g. air/oil etc.).

30
31 The spectrometric analysis of the data acquired by the
32 radar apparatus is performed on a computer which is

1 capable of running a suitable software program to
2 implement the required analysis.

3
4 The frequency response obtained by irradiating a
5 substance displays characteristics which the inventor
6 believes are at least partially dependent on the
7 interaction of the transmitted signal with the sub-
8 atomic structure of the substance to be analysed. The
9 radar apparatus may further include suitable filter
10 devices to control the spectral characteristics, for
11 example bandwidth and/or polarisation, of the signals.

12
13 Optionally, the radar signal may be transmitted into a
14 chamber capable of holding a sample of the substance.

15
16 In certain embodiments of the invention, the
17 transmitted signal is controlled so that resonant
18 conditions, i.e. standing waves, are set up within the
19 radar apparatus. Preferably, the resonant conditions
20 occur within transmitting/receiving cavities
21 surrounding the antennae. Further resonant conditions
22 may be generated within the substance and/or within a
23 chamber enclosing the substance. Such resonant
24 conditions may be established by selectively tuning the
25 parameters of the emitted signal until the spectrum of
26 the received signal indicates resonant conditions.

27
28 The radar apparatus is preferably configured so as to
29 be capable of providing a highly collimated or
30 selectively focussed beam over a desired range.

31

1 The boundary conditions for resonant standing waves are
2 at least partially dependent on the surface boundaries
3 of the substance itself, and may be further affected by
4 any internal structure within the substance. Composite
5 materials, for example, may exhibit more complex
6 boundary conditions which can enable the structure of
7 the substance to be determined; for example, the degree
8 of granularity of a powdered sample may be determined
9 to some extent using the radar apparatus.

10

11 The invention, in its various aspects, variants and
12 optional and preferred features, is defined in the
13 Claims appended hereto.

14

15 Embodiments of the invention will now be described, by
16 way of example only, with reference to the accompanying
17 drawings in which:

18

19 Fig 1 is a block diagram of a radar system embodying
20 one aspect of the present invention;

21

22 Fig 2 is a block diagram of a preferred embodiment of a
23 radar system similar to that of Fig. 1;

24

25 Figs. 3A and 3B are cross-sections of test chambers
26 incorporating receiving and transmitting antennas
27 embodying another aspect of the invention;

28

29 Fig. 4 is an exploded internal plan-view of the test
30 chamber illustrated in Fig. 3A;

31

1 Fig. 5A is a cross-sectional side view of an antenna
2 assembly for use as a transmitter or receiver embodying
3 a further aspect of the invention;

4

5 Fig. 5B is a cross-sectional side view of a first
6 variant of the antenna assembly of Fig. 5A;

7

8 Fig. 5C is a cross-sectional side view of a second
9 variant of the antenna assembly of Fig. 5A;

10

11 Fig. 5D is a cross-sectional side view of a third
12 variant of the antenna assembly of Fig. 5A;

13

14 Fig. 5E is a cross-sectional side view of an antenna
15 assembly for use as a transmitter or receiver, similar
16 to that of Fig. 5A;

17

18 Figs. 5F to 5N are schematic end views illustrating
19 variants of antenna assemblies of the type shown in
20 Fig. 5E;

21

22 Fig 6A is a cross-sectional view of radar apparatus set
23 up for chamber mode operation according to one
24 embodiment of the invention;

25

26 Fig. 6B is a cross sectional view of apparatus set up
27 according to a variation of the embodiment of Fig. 6A;

28

29 Fig. 7A illustrates an example of an arrangement of
30 radar apparatus for operation in a reflection mode in
31 accordance with a further embodiment of the invention;

32

1 Fig. 7B illustrates a further arrangement of radar
2 apparatus for operation in a transillumination mode in
3 accordance with a further embodiment of the invention;

4
5 Figs. 8A to 8D are sketches which illustrate various
6 embodiments of the invention suitable for the remote
7 detection and/or imaging and/or typecasting of
8 substances/objects;

9
10 Fig. 9 is a sketch illustrating an embodiment of radar
11 apparatus in accordance with the invention suitable for
12 sea-bed scanning;

13
14 Fig. 10 is a sketch illustrating another embodiment of
15 apparatus embodying the invention suitable for sea-bed
16 scanning;

17
18 Fig. 11A shows an example of a microscope fitted with
19 transmitting and receiving antenna assemblies in
20 accordance with a further embodiment of the invention.

21
22 Fig. 11B illustrates the relative movement of a
23 transmitting antenna and receiving antenna in
24 accordance with a further embodiment of the invention.

25
26 Fig. 12 is a table summarising various parameters as
27 used in a variety of embodiments of the invention.

28
29 Fig. 13 is an image recorded using the radar apparatus
30 according to the invention.

31

1 Firstly, apparatus embodying various aspects of the
2 invention will be described.

3
4 Fig. 1 is a generic block diagram illustrating the
5 basic architecture of radar systems in accordance with
6 the invention. A pulsed radar unit 21 is powered by a
7 power supply 20. The radar unit 21 is connected to a
8 transmitting ("Tx") antenna assembly or antenna array 2
9 and to a receiving ("Rx") antenna assembly or antenna
10 array 3. The radar unit 21 may be of a conventional
11 type, suitably a Ground Penetrating Radar (GPR) set,
12 capable of providing controlled signal pulses to the Tx
13 antenna assembly 2 and of receiving and processing
14 return signals received by the Rx antenna assembly 3
15 and includes suitable input/output means to transmit
16 and receive pulsed signals. The general configuration,
17 controls etc. of radar sets of this type will be well
18 known to persons skilled in the art and will not be
19 described in detail herein. The controls of the radar
20 unit 21 enable the characteristics of the transmitted
21 pulse to be controlled, such characteristics including,
22 for example, the pulse profile, width, duration and
23 energy. For the purposes of the present invention, the
24 radar set 21 acts primarily as a pulse generator for
25 driving the Tx antenna.

26
27 The radar unit 21 is connected to an analog/digital
28 (A/D) converter 22 and control unit 25, for controlling
29 the operation of the radar unit 21 and for receiving
30 analog signals received by the radar unit via the Rx
31 antenna 3 and for converting the analog signals to
32 digital form. The A/D converter and control unit 22,25

1 are in turn connected to signal processing and display
2 means 23, typically comprising a suitably programmed
3 personal computer, with associated data storage means
4 24 of any suitable type(s) (hard disk and/or tape
5 and/or writable CD-ROM etc.). The computer 23 generally
6 includes a suitable visual display device (not shown).

7
8 The power supply means 20 may be a mains supply, or a
9 generator and/or a battery supply. The power supply
10 means 20 may be provided internally within the pulse
11 generation unit 21 or externally. Typically, the power
12 supply means 20 is a 12 volt DC supply which may be a
13 mains supply converted to 12 V DC, or alternatively,
14 especially in portable embodiments of the invention, be
15 a 12V generator and/or a 12V DC battery supply.

16
17 The radar unit, A/D converter and control unit and the
18 computer may be combined in a variety of configurations
19 in custom built apparatus. As illustrated, the system
20 preferably comprises a standard radar unit, a standard
21 computer with software suited to the methods of the
22 present invention, and a purpose built A/D converter
23 and control unit.

24
25 The computer is suitably a ruggedised portable computer
26 (laptop) with a suitably powerful processor, e.g. a
27 Pentium-type processor, and adequate memory (RAM) and
28 mass storage capacity.

29
30 The A/D converter 22 is preferably designed so that in
31 use it is capable of receiving at least three signal

1 inputs. An additional signal input, for example a voice
2 data input, may also be provided.

3

4 The system is operable in at least one of three general
5 modes of operation, in accordance with the invention:

6 "chamber" modes in which a sample of material under
7 investigation is enclosed in a chamber, the Tx antenna
8 being arranged to irradiate the interior of the chamber
9 and the Rx antenna being arranged to receive signals

10 modified by the interaction of the transmitted signals
11 with the chamber and its contents; "transillumination"

12 modes in which the Tx antenna is arranged to transmit
13 signals through a sample of material or an object, body
14 or structure etc. under investigation and the Rx

15 antenna is arranged to receive signals which have
16 passed through the sample, object etc.; and

17 "reflection" mode in which the Rx antenna receives

18 signals transmitted by the Tx antenna and reflected by
19 a sample, object, body or structure etc. These various

20 modes of operation will be discussed in more detail

21 below. The various modes of operation are used for a

22 variety of imaging, mapping, measuring and typecasting

23 functions, as shall also be described in more detail

24 hereinafter.

25

26 Fig. 2 illustrates a preferred embodiment of a multi-
27 purpose radar system in accordance with the invention

28 which can employ a variety of types of transmitting and
29 receiving antennas, antenna assemblies or antenna

30 arrays, including the preferred antennas and antenna

31 assemblies described hereinbelow.

32

1 Referring to Fig. 2, the system comprises a radar
2 control unit (RCU) 500, a computer 506, a transmitter
3 unit 507, a receiving unit 508, a transmitting antenna
4 550, a receiving antenna 552 and a power supply 519.

5
6 The RCU has its own motherboard with a processor 501,
7 DMA controller 502, a buffer memory module 503 and an
8 input/output controller 504, all linked to a system bus
9 505. The I/O controller 504 is directly connected to
10 the external computer 506, which controls all digital
11 set-ups, data storage and data analysis. The RCU 500
12 provides the timing signals for controlling the
13 transmitting and receiving units 507 and 508, which are
14 directly linked to the transmitting and receiving
15 antennas 550, 552. The antennas 550, 552 may be single
16 or multiple elements. The timing signals are
17 controlled by parameters output from the computer 506
18 to the RCU 500. The RCU 500 also relays digitised data
19 from the receiver unit 508 back to the computer 506.
20 The RCU 500 consists of analogue and digital logic with
21 a programmable central processing unit (CPU) 501.

22
23 The RCU sets up a Pulse Repetition Frequency (PRF).
24 The transmitter unit 507 essentially consists of a
25 pulse generator 512 designed to produce strong pulses
26 with characteristics, including the PRF, determined by
27 the RCU. The pulse is limited by the high voltage,
28 current and power required. Extending the pulse width
29 reduces the voltage and current needed for the same
30 average pulse energy. Too short a pulse will produce
31 too much high frequency energy which is not necessary
32 for certain applications in which high frequencies are

1 absorbed more than the lower frequencies in the subject
2 under examination (e.g. the ground in sub-surface
3 ground applications). Higher frequencies may be
4 required for other applications including shallow range
5 modes of operation (e.g. for microscopic slide scanning
6 applications in medical tissue studies).

7

8 In the transmitter unit 507, the pulse is triggered by
9 a digital "Trig in" pulse sent from the RCU 500, via a
10 PRF module 509 which channels the Trig in pulse through
11 a fixed delay line 510. The Trig in pulse 511 is
12 responsible for triggering the transmitted pulse in the
13 transmitter unit 507. A delay/gain control 513 in the
14 RCU 500 controls a gain control 514 to generate a fixed
15 time varying gain (TVG) and fixed delay line 510 for
16 the transmitter unit 507. The same delay/gain control
17 513 operated upon by the PRF module 509 also creates a
18 variable TVG for the receiver unit amplifier 518 and a
19 variable delay line 515 for a sample and hold module
20 516 of the receiver unit 508. The rate at which pulses
21 are transmitted is referred to as the pulse repetition
22 frequency (PRF) and the PRF module 509 sets the
23 required PRF for each particular mode of operation of
24 the system. The PRF must be long enough to allow
25 analogue to digital (A/D) conversion to be performed by
26 the A/D converter 517 of the receiver unit 508 and to
27 cover the required time window for the particular
28 instrument measuring application.

29

30 The receiver unit 508 includes a low noise amplifier
31 518 which amplifies the analogue signal received via
32 the receiver antenna 552, which is sampled by the

1 sample and hold module 516 and digitised by the A/D
2 converter 517 when requested by a digital signal from
3 the RCU 500.

4

5 The A/D converter 517 is responsible for analogue to
6 digital sampling and the digital sampling frequency
7 should ideally be no greater than the time spacing
8 between picture elements (pixels) of the output signal
9 data. A smaller sampling interval results in aliasing
10 (i.e. increasing noise) of the signal. A longer
11 sampling interval attenuates the higher frequency
12 components of the signal. The advantage of the
13 variable TVG from the gain control 514 to the receiver
14 amplifier is that the A/D conversion may be performed
15 to the same precision with a lower number of bits.

16

17 The digital data obtained from the A/D converter enable
18 real-time analysis of

- 19 i) a positioning fix sign or chainage mark, enabling
20 the location of a substance/image to be determined;
21 ii) imaging signal information;
22 iii) typecasting information - i.e. the spectral
23 characteristics of the scanned substance/object;
24 iv) a voice-over to be further recorded from the user
25 via a suitable microphone as a digital signal.

26

27 In use of the radar apparatus, the A/D converter
28 converts the received signal from analogue format to a
29 12-bit digital signal and combines this with a synch
30 pulse and electronic fix data. The signal is buffered
31 and synchronised with a 16 bit computer signal to

1 condition the data. Image data are converted into 8-bit
2 image files.

3

4 The computer 506 controls the overall functions of the
5 other units and provides a user interface for the
6 selection of control and survey parameters, data
7 collection, data enhancement, image production, image
8 analysis, material typecasting, material testing and
9 data logging etc..

10

11 The entire radar system is powered either by mains
12 power 519 or battery power conversion 520.

13

14 There are four primary signal, data and control
15 linkages between the components of the system:
16 transmitter 507 to receiver 508, RCU 500 to transmitter
17 507, receiver 508 to RCU 500, and RCU 500 to computer
18 506. The transmitter to receiver linkage is via the
19 antennas 550, 552 and intervening media such as air or
20 other gases, water or other liquids, the ground, vacuum
21 etc. There may also be unintentional transmitter-
22 receiver linkage through RCU-transmitter cables and
23 receiver-RCU cables if they are conducting. When this
24 occurs, touching the cables may cause an electrical
25 short which can affect output data. The RCU-
26 transmitter and receiver-RCU linkages will generally be
27 metal or glass fibre, but can be wireless connections
28 such as radio or optical through vacuum and/or gaseous
29 and/or liquid media. Metal is preferably avoided for
30 the above mentioned reasons. The RCU-computer linkage
31 will normally be a serial or parallel port connection,
32 since the required data rates are not unusually high.

1 Other possible links include USB, PCMCIA, IrD or radio
2 modem.

3
4 Examples of various antennas and antenna assemblies,
5 embodying further aspects of the invention, will now be
6 described, which are particularly suited for the
7 purposes of the invention when operated in one or more
8 of its various modes.

9
10 Figs. 3A, 3B and 4 illustrate examples of
11 antenna/chamber assemblies suited for chamber mode
12 operations in accordance with the invention,
13 particularly for typecasting applications performed on
14 material samples or relatively small objects.

15
16 Fig. 3A shows a cross-section through a sample
17 irradiation chamber 100a which has a preferred
18 pyramidal geometry. Fig. 3B shows a cross-section
19 through a sample irradiation chamber 100b which has an
20 upper section with a pyramidal geometry similar to that
21 of Fig. 3A but with a rectangular chamber extending
22 downwardly from the base of the pyramid. Fig. 4 shows
23 an exploded overhead view of the embodiments
24 illustrated in Figs. 3A and 3B indicating the antenna
25 configuration.

26
27 The cross-section along lines X-X' of Fig. 4 is
28 illustrated in Fig. 3A. In Fig. 4. A transmitting
29 antenna 102 and a receiving antenna 103 are directly
30 provided within the chambers 100. Fig 3A shows the
31 configuration of the transmitting antenna 102 in
32 profile. A cathode feed connector wire 111 connects a

1 cathode half of a transmitting bowtie dipole element
2 115a to the pulse generator of the system. An anode
3 feed connector wire 112 connects the anode half of the
4 transmitter bowtie element 115b provided on the
5 opposite internal face of the chamber 100 to the
6 receiver side of the system.

7
8 Fig. 4 illustrates the orientation of a receiving
9 cathode bowtie dipole component 120a and connecting
10 cathode feed connector wire 118 and a receiving anode
11 bowtie dipole component 120b and connecting anode feed
12 connector wire 119.

13
14 To increase the detection of cross-polarised
15 reflections and to reduce the detection of other
16 reflections, the receiver dipole components 120a, 120b
17 are orientated at 90° to the transmitter dipole
18 components 115a, 115b.

19
20 To ensure that a sample of material 116 placed within
21 the chamber 100 (as Fig. 3A and 3B show) is
22 sufficiently irradiated, the chamber 100 is provided
23 with a suitable geometry to enhance the internal
24 reflection and is suitably sealed to eliminate
25 radiation leaks. Alternatively the chamber and/or
26 transmitter/receiver tubes are vacuum sealed. A wall
27 113a or base 113b of the chamber 100 is configured so
28 that access to the interior is provided so as to enable
29 the sample 116 to be placed inside. For example, the
30 entire base 113b of the chamber 100 may be detachable.

31

1 Radiation shielding of the interior and the elimination
2 of any radiation leaks from the interior is provided by
3 the selection of suitable construction materials for
4 the chamber 100. For example, the walls 113a and base
5 113b of the chamber 100 may be constructed from an
6 insulating material such as plastic, and may be bonded
7 externally or internally to an electrically conducting
8 material such as copper 114. Alternatively, the base
9 113b may be made of a metallic substance to optimise
10 base reflections.
11

12 In the Fig. 3B chamber, to ensure that the optimal
13 number of reflections occur in the chamber interior,
14 the rectangular side walls 122 are preferably provided
15 with a metallic inside surface. This enables omni-
16 directional backwall and base reflections from the
17 transmitted radiation to penetrate the sample. The
18 geometry of the chamber 100 is preferably selected to
19 maximise the irradiation of the sample. As Figs. 3A
20 and 3B show, the primary direction of the radiation
21 pattern is orientated to and from the walls 113, base
22 123 and the sample 116.
23

24 Figs. 5A to 5D are cross-sectional side views of
25 preferred embodiments of antenna assemblies in
26 accordance with one aspect of the invention which can
27 be deployed as receivers and/or transmitters in various
28 systems and methods embodying the invention. These
29 embodiments are applicable to all of the various
30 operational modes and functions in accordance with the
31 various aspects of the invention; i.e. chamber,
32 transillumination and reflection modes and

1 imaging/mapping and typecasting functions. The
2 configuration of the antenna assemblies is scalable
3 over a wide range of dimensions for different
4 applications.

5
6 At the front end 203 of the assembly, a focusing system
7 is provided by a suitable lens device 204, for example
8 of the type of a Fresnel Zone Plate (FZP) lens. The
9 FZP lens comprises two concentric slit-ring apertures
10 224, 225 separated by a ring spacer 226, for example a
11 metallic (e.g. polished brass) front-end internal
12 reflecting ring. The main body of the assembly
13 consists of a tube 227, preferably having a reflective
14 metallic composition, for example polished brass or
15 stainless steel. A back wall reflector 232 is provided
16 in the form of a concave metallic ring (again polished
17 brass or any other suitably reflective material may be
18 used) which is bonded to the tube 227 and to a cathode
19 connector 233. Through the centre of the backwall
20 reflector 232 protrudes an anode element 230, which is
21 preferably a narrow hollow tube element, for example
22 comprising copper, and which is separated from the
23 grounded cathode walls of the assembly by insulating
24 material 231.

25
26 The diameter D_A of the anode element 230 is preferably
27 an exact multiple of the internal diameter D_T of the
28 tube 227. The un-insulated portion of the anode element
29 230 also protrudes into the interior of the tube 227 by
30 a distance L_A which is preferably an exact multiple of
31 the total reflecting distance L_T from the back wall
32 reflector 232 to the front wall reflecting ring 226.

1
2 For example, an anode width of 2 mm and a tube inner
3 diameter of 10 mm gives a ratio $D_A:D_T$ of 1:5. Ideally,
4 the ratios between the anode diameter and the tube
5 diameter are integers and similarly the ratios between
6 the anode length and the tube length are integers. In
7 this case, an anode length L_A of 19.05mm and a tube
8 inner length L_T of 190.5 mm between the back wall
9 internal reflector 232 and front wall internal
10 reflector 226 gives a longitudinal standing wave ratio
11 parameter of $L_A:L_T$ of 1:10. This balances the lateral
12 ratio parameter $D_A:D_T$ of 1:5 to achieve optimum standing
13 wave resonance in the tube, before the wave is launched
14 through the aperture.

15
16 These proportions are selected to optimise resonant
17 reflection conditions in the assembly. The resonant
18 amplification effect and the propagation of signals
19 through the assembly is further optimised by the
20 appropriate selection of a dielectric cladding material
21 228 which substantially fills the interior of the tube
22 227 (and, preferably, the interior of the tube forming
23 the anode 230, in order to maximise the effective
24 dielectric constant of the assembly for a given
25 dielectric material). The cladding material 228
26 preferably has a high dielectric constant to provide an
27 optimum resonant amplification through the antenna
28 assembly. The dielectric material may be a liquid or a
29 solid or a mixture thereof. Preferably, the dielectric
30 material comprises a powdered solid packed within the
31 interior of the tube 227.

32

1 An anode feed wire connects the anode element connector
2 236 to a highly resistive (e.g. 75 Ω) lead cable 235.
3 The back reflector 232 is grounded by connecting a
4 ground wire from the lead cable 235 to the cathode
5 element connector 237.

6
7 The configuration of the assembly is such that the
8 transmitted energy radiated from the anode 230 is
9 highly collimated within the body of the assembly.
10 When the assembly is used as a transmitter the
11 concentric focussing ring slits 224, 225 at the
12 transmitting end have the effect of focussing the
13 collimated beam exiting the assembly at a predetermined
14 distance from the exit aperture. Depending on the
15 configuration of the focussing ring slits, and/or the
16 use of additional focussing elements such as dielectric
17 lens attachments described below, the characteristics
18 of the transmitted beam can be modified so that the
19 focal distance of the assembly may be varied over a
20 wide range, effectively from the exit aperture to
21 infinity, for different applications.

22
23 Fig. 5B shows an antenna assembly similar to that of
24 Fig. 5A, which further includes a cylindrical
25 dielectric lens element 238 with planar end surfaces.
26 This type of lens attachment modifies the beam leaving
27 the assembly in a manner which depends on the distance
28 of the outer end surface of lens attachment relative to
29 the inherent focal distance of the main assembly, and
30 on the refractive index and dielectric properties of
31 the lens attachment relative to those of the dielectric

1 cladding material inside the assembly and relative to
2 those of the external medium/media into which the beam
3 is transmitted from the device. This embodiment is
4 particularly useful when the lens surface is located at
5 the inherent focal distance of the assembly and placed
6 in contact with a surface under examination, acting as
7 a spacer element for precise focussing.

8
9 Fig. 5C shows a further antenna assembly similar to
10 that of Fig. 5A. In this case the assembly is fitted
11 with a cylindrical plano-concave dielectric lens 239.
12 As compared with the embodiment of Fig. 5B, this type
13 of lens attachment further modifies the beam depending
14 on the geometry of the concave surface, in addition to
15 its refractive and dielectric properties. A beam
16 emerging from the embodiment of Fig. 5A will diverge
17 beyond the focal distance of the assembly. A plano-
18 concave lens of this type may be configured to reduce
19 such divergence or to re-focus the beam or to collimate
20 the beam.

21
22 Fig. 5D shows still another antenna assembly similar to
23 that of Fig. 5A. In this case the assembly is fitted
24 with a cylindrical plano-convex dielectric lens 240.
25 This type of lens attachment will have an effect
26 opposite to that of Fig. 5B. When the assembly is used
27 as a receiver, it will increase the capacity of the
28 assembly to collect incident radiation.

29
30 In the embodiments of Figs. 5A to 5D, the tubular body
31 of the assembly acts as the cathode of the antenna and
32 the anode extends along the central longitudinal axis

1 of the tube. Fig. 5E shows an alternative embodiment,
2 similar to that of Fig. 5A except that both the anode
3 and cathode both comprise elongate, preferably tubular,
4 elements 602, 604 located inside the outer tube 606,
5 parallel to and arranged symmetrically about the
6 longitudinal axis thereof. The dimensions
7 (particularly the lengths and diameters) of the anode
8 and cathode elements 602 and 604 are preferably
9 proportional to the corresponding dimensions of the
10 tube 606, as with the anode of the embodiments of Figs.
11 5A - 5D. Also, the spacings between the elements 602
12 and 604 and between the elements and the outer tube 606
13 are similarly in proportion.

14
15 The arrangement of the antenna elements 602 and 604 in
16 Fig. 5E allows a pair of similar antenna assemblies to
17 be cross polarised relative to one another since the
18 assemblies can be rotated about their longitudinal axes
19 such that the planes in which the elements 602 and 604
20 of each assembly lie can be arranged at right angles to
21 one another.

22
23 The number and arrangement of anode and cathode
24 elements within the antenna assemblies may be varied,
25 as illustrated in Figs. 5F to 5N, which are schematic
26 end views of antenna assemblies similar to those of
27 Fig. 5E with different arrangements of elements. Figs.
28 5F and 5I show assemblies similar to those of Fig. 5E
29 with one anode and one cathode element 602 and 604. In
30 Fig. 5F, the elements are oriented at right angles to
31 those of Fig. 5I. Figs. 5G, 5H 5J and 5K show
32 assemblies with multiple anode and cathode elements

1 arranged in linear arrays along a diameter of the outer
2 tube of the assembly, with Figs. 5G and 5H showing the
3 arrays oriented at right angles to those of Figs. 5J
4 and 5K. Figs. 5L to 5N show further embodiments with
5 multiple elements arranged in cruciform arrays, the
6 elements being located along two diameters of the tube
7 at right angles to one another. In such embodiments,
8 the arrangement of anodes and cathodes may vary. For
9 example, the elements along one diameter may all be
10 anodes and the elements along the other diameter may
11 all be anodes, or the elements located along two
12 adjacent radii may be anodes and the elements located
13 along the other two radii may be cathodes, allowing
14 different polarisations of respective assemblies.
15 Pairs of assemblies may be oriented with the planes of
16 their arrays disposed at relative angles other than 90° ,
17 such as 45° , so as to provide other relative
18 polarisations. Electrical connections to the various
19 elements may be switchable so that a single assembly
20 may be selectively configured with different
21 arrangements of anodes and cathodes. In all cases, the
22 relative dimensions and spacings of the elements and
23 the outer tube are preferably in proportion as
24 previously described.

25
26 The various basic modes of operation of radar systems
27 in accordance with the invention will now be described.

28
29 Figs. 6A and 6B illustrate "chamber" modes, in which a
30 sample of material or the like is enclosed in a
31 chamber. These embodiments operate by
32 "transilluminating" the sample. The embodiments of

1 Figs 3 and 4 are also intended for chamber mode
2 operation, but do not transilluminate the sample in the
3 same way as the embodiments of Figs 6A and 6B.

4

5 Referring now to Fig. 6A, a cross-section of two
6 antenna assemblies similar to those of Fig. 5E is
7 illustrated, arranged for chamber mode operation.

8

9 The apparatus shown generally at 1 consists of a
10 transmitter assembly 2 and a receiver assembly 3
11 aligned substantially coaxially with a chamber 4
12 provided in co-alignment therebetween.

13

14 The transmitter 2 and receiver 3 each consist of a
15 cavity 5a and 5b respectively, for example a hollow
16 tube or pipe. Within the tube 5a, an anode 6a and
17 cathode 7a form a transmitting antenna 8a which is
18 disposed in longitudinal alignment with the tube axis
19 XX'. Within tube 5b, an anode 6b and cathode 7b form a
20 receiving antenna 8b which is disposed in longitudinal
21 alignment with the tube axis XX'.

22

23 Within each tube 5a, 5b, the anodes 6a, 6b and cathodes
24 7a, 7b are substantially surrounded by a cladding
25 material selected for its dielectric properties. For
26 example, the antennae 8a, 8b can be immersed in
27 distilled water which is used as a dielectric cladding.
28 Other alternatives include mixtures of distilled water
29 and sand, or any other substance having the desired
30 dielectric properties. Each tube 5a, 5b is suitably
31 sealed at each end 12a, 13a and 12b, 13b respectively.

1 A suitable sealant is, for example, a resin or other
2 electrically insulating substance,
3

4 Focusing means 9a, 9b are provided adjacent to the
5 chamber 4. In this case, each of the focusing means 9a
6 or 9b comprises a dielectric lens of a selected
7 geometry and dielectric composition to enable the
8 radiation emitted/received by the respective
9 transmitting antenna 8a or collecting antenna 8b to be
10 converged/diverged as it enters/exits the chamber 4
11 respectively. For example, in this first embodiment of
12 the invention, the lenses 9a, 9b of the transmitter and
13 receiver respectively are both selected to have a wax
14 composition with a high resistivity, for example, of
15 the order of 10^9 Megohm-meters.
16

17 The relative dimensions of each anode 6a, 6b to the
18 corresponding cathode 7a, 7b and the surrounding
19 dielectric material and/or tube 5a, 5b are determined to
20 be fractionally proportional to each other as
21 previously described. For example, the width of the
22 anode 6a is proportional to the width of the cathode 7a
23 and to the interior diameter of the tube 5a and the
24 length of the anode 6a is proportional to the overall
25 length of the tube 5a.
26

27 It is believed that such geometrical scaling between
28 the antenna and the surrounding cladding, together with
29 the dielectric properties of the cladding, assists the
30 formation of resonant standing wave oscillations.
31 Standing wave oscillations set up within the dielectric
32 material contained within the transmitting tube 5 can

1 assist in the intensification and collimation of the
2 emitted radiation. Under such conditions, the
3 transmitter 2 provides a means of generating a resonant
4 and collimated beam of radiation at selected
5 wavelengths which the receiver 3 is capable of
6 detecting.

7
8 The overall geometry of the transmitter 2 and receiver
9 3 are therefore related to the size and scale of
10 resolution required. The dielectric properties of the
11 cladding material selected to surround the antennas 8a,
12 8b are also important in this respect as these will
13 affect the group velocity V_g of the radiation
14 emitted/received.

15
16 In the embodiment illustrated in Fig. 6A, the
17 transmitter 2 and receiver 3 are arranged in coaxial
18 alignment so that the sample chamber 4 is
19 transilluminated.

20
21 To typecast a substance by determining its spectral
22 characteristics, other selection criteria may be used
23 to determine suitable antenna cladding materials and
24 the relative dimensions and overall size of the antenna
25 assemblies. In each case the object is to ensure
26 sufficient spectral detail is obtained at the desired
27 resolution and scale. To ensure optimum conditions, it
28 is preferable for the widths/lengths of the tubes 5a,5b
29 to be integral multiples of the widths/lengths of the
30 internal antennas 8a and 8b respectively.

31

1 Returning to Fig 6A, in this embodiment of the
2 invention the radar equipment 1 is operated to
3 typecast/identify a sample 10 placed within the chamber
4 4. The chamber 4 in this embodiment is disposed in two
5 parts: a lower portion 4a attached to the transmitter 2
6 and an upper portion 4b attached to the receiver 3.
7 The sample 10 is placed in the lower portion 4a.
8 For example, the chamber may have an internal diameter
9 of 40 mm and an internal depth of 40mm above the tube
10 base.

11
12 In this embodiment, the tubes 5a,5b may each have an
13 internal diameter of 16mm, and the chamber 4 is
14 positioned so that the overall inner transmission
15 length of the transmitter tube 5a and chamber portion
16 4a is 330mm and the overall receiver length of the
17 receiving tube 5b and chamber portion 4b is 295mm. The
18 measurements in each case are parallel to the direction
19 XX' and are measured from the contact interface between
20 the lower chamber portion 4a and the upper chamber
21 portion 4b when the chambers contact each other in the
22 transillumination configuration. For a required
23 internal chamber volume, the dielectric lenses 9a, 9b
24 are selected to optimise the convergence/divergence of
25 radiation emitted by the antenna assemblies 2,3 and the
26 sample chamber portion 4a is located within a maximum
27 distance from the transmitter 2, preferably no more
28 than 300mm.

29
30 In the embodiment illustrated in Fig. 6A, each antenna
31 8a, 8b may be a multi-folded YAGI array with two
32 insulated groups containing a plurality of individually

1 screened high quality copper elements in the
2 longitudinal tube plane XX'. Each array is filled with
3 the selected dielectric material, such as distilled
4 water in this example, to make a dielectrically clad
5 bistatic antenna pair. The above configuration enables
6 an optimum impedance match to be obtained at 50 ohm.

7
8 The radiation emitted by the transmitting antenna 8a is
9 focused by means of the wax lens 9a so that the sample
10 placed in the lower portion of the chamber 4a is
11 irradiated. Each wax lens 9a, 9b in this embodiment
12 extends 4mm into the base of the chamber portions 4a,
13 4b respectively. The receiving portion of the chamber
14 4b is filled with a suitable dielectric, for example,
15 air. The radiation is refocussed by the wax lens 9b
16 into the receiving antenna assembly 2 where it is
17 detected by the receiving antenna 8b.

18
19 In this embodiment, the size of the chamber 4 limits
20 the size of objects to be examined: apart from this
21 limitation a variety of substances may be typecast
22 ranging, for example, from solid materials or
23 composites, liquids, gases, soils, sediments or powder
24 samples. For example, wood powders, soils, flours and
25 oils. Both organic and non-organic substances can be
26 typecast.

27
28 As an example, if the total volume of the sample
29 chamber 4 is 45ml, a sample of, for example, 25ml of
30 the substance to be typecast may be placed within the
31 lower portion of the chamber 4a. Air occupies the

1 remaining 20ml volume of space inside the upper chamber
2 portion 4b.

3
4 To ensure that stray e.m. radiation is reduced to a
5 minimum, suitable e.m. shielding is provided. For
6 example, by selecting a conductive, metallic substance
7 (e.g. aluminium) to form the tubes 5a,5b and chamber
8 portions 4a,4b and/or by further sheathing the metallic
9 substance with a suitable insulating material (e.g.
10 plastic). The provision of a layer of insulating
11 material and conductive material is as is known in the
12 art such that stray e.m. fields etc. are substantially
13 eliminated.

14
15 The transmitter antenna assembly 2 is used to generate
16 a resonant collimated beam of pulsed radar signals.
17 These pulsed signals are set up and controlled by a
18 pulse generator unit as previously described in
19 relation to Figs. 1 and 2. In this example, the
20 bandwidth of the transmitted pulse may be of the order
21 of 2 MHz to 200 MHz. A large enough time window is
22 employed to ensure that sufficient reflections have
23 occurred within the telescopes 2, 3 and the chamber 4.
24 For example, a time window of 16ns can be used with a
25 pulse interval time of 100ms.

26
27 Fig. 6B shows another embodiment which is a variation
28 of the arrangement of Fig. 6A. In Figs. 6A and 6B,
29 like reference numerals designate like or equivalent
30 components and features. In this embodiment, the
31 transmitting and receiving antenna assemblies 2 and 3
32 are again aligned in transillumination mode, with an

1 enclosed chamber 4 which completely contains and
2 conceals a sample container 400 for specimen
3 typecasting. In this example the transmitting and
4 receiving antenna assemblies may be similar to those of
5 Figs. 5A and 5B. This embodiment differs from that of
6 Fig. 6A in that interior cavities of the tubes 5a and
7 5b are packed with a high dielectric material, such as
8 barium titanate, for which ϵ_r equals 4000 at room
9 temperature. Within the tubes 5a, 5b, the anodes 6a,
10 6b are located centrally, extending along the axis X-
11 X', and the cathodes 7a, 7b are provided by the inner
12 walls of the tubes 5a, 5b.

13

14 The focussing means 9a, 9b preferably touch the top and
15 bottom respectively of the sample container 400. In
16 this case, the focussing means 9a, 9b comprises two
17 concentric slit-ring apertures 224a, 224b, 225a and
18 225b, separated by a spacer 226a, 226b, as described
19 above in relation to Fig. 5.

20

21 The chamber 4 in this case comprises two metallic solid
22 cells 4a, 4b screwed together to form a sealed radio
23 frequency (RF) shielded unit. The cells 4a, 4b are
24 preferably made from non-magnetic metals, such as
25 aluminium or brass, for example.

26

27 This arrangement of the typecasting chamber has been
28 optimised to substantially eliminate stray
29 electromagnetic fields.

30

1 The bandwidth of the signals received depends on the
2 size and configuration of the antennas 8a,8b and the
3 sample chamber 4. If the sample substance is to be
4 typecast, its spectral characteristics are determined
5 by subtracting the signal received from the apparatus
6 under resonant conditions when the sample chamber 4 is
7 empty from the signal received under similar conditions
8 when a substance to be typecast is placed within the
9 chamber 4. The spectral characteristics of the
10 resultant data may then be compared with the spectral
11 characteristics of known materials which have
12 previously been obtained in a similar manner and stored
13 in a database.

14
15 It is important to provide a sufficiently long time
16 window for the radiation pattern created within the
17 test chamber 4 to create resonant conditions within the
18 sample (this also applies to other typecasting modes of
19 operation as shall be described below). The
20 transmitted radar pulse may be tuned so that the
21 detected signal indicates that a suitable resonant
22 radiation conditions have been established.

23 The second mode of operation relates to the use of
24 antenna assemblies 200, such as those illustrated in
25 Fig. 5, being deployed in a transillumination
26 configuration, without the use of a sample chamber,
27 such as that illustrated in Fig. 6B, which shows
28 axially aligned Tx and Rx antenna assemblies 201, 202,
29 such as those of Figs. 5A - 5N. It will be understood
30 that transillumination modes of operation do not
31 necessarily require the Tx and Rx antennas to be
32 axially aligned. The antennas may be parallel or at an

1 angle to one another on one side of the object etc
2 under examination, with a reflector placed behind the
3 object so that the signal from the Tx antenna passes
4 through the object and is reflected back to the
5 receiver by the reflector.

6

7 As shown in Fig. 7B, the assemblies are co-axially
8 aligned to face one another and are placed at an
9 optimal focusing separation with a test
10 substance/object located mid-way between the two
11 sensors in order to achieve a balanced
12 transillumination effect. Assemblies of this type may
13 also be used in the arrangements illustrated in Figs 6A
14 and 6B.

15

16 In this mode, the apparatus provides a means to image
17 or typecast the internal composition or contents of,
18 for example, baggage on a conveyor belt. In such an
19 application, the antenna assemblies 201, 202 are
20 arranged on either side of the belt to transilluminate
21 baggage as it moves along the belt. Metallic
22 reflectors may be further provided below the belt and
23 around the sides/roof of any surrounding shield.

24

25 The third mode of operation relates to the antenna
26 assemblies 200 being deployed in a parallel
27 configuration or at an angle to one another with the
28 apertures of the Tx and Rx antenna assemblies facing
29 the same direction and the received signal having been
30 deviated back towards its source direction (e.g.
31 reflected or backscattered). Figs. 7A, 8A to 8D, 9 and
32 10 illustrate examples of this mode of operation. The

1 antenna assemblies may be deployed in a stationary
2 configuration or one or both of the antenna assemblies
3 may move relative to the substance/area to be scanned
4 and/or the substance/area may be moved relative to the
5 antenna assemblies.

6
7 For example, Fig 7A is a schematic diagram illustrating
8 the arrangement of the receiving and transmitting
9 antenna assemblies 201, 202 as described above, in a
10 GPR application suitable for remotely detecting and/or
11 imaging and/or typecasting objects and/or substances
12 located underground. The transmitter assembly 201 and
13 the receiver assembly 202 may be mounted on suitable
14 land and/or sea vehicles. For example, Fig 8A
15 illustrates how the apparatus may be mounted on to the
16 rear or front of a land vehicle. Alternatively, the
17 apparatus could be provided to protrude through the
18 floor or hull of a sea-vehicle such as Fig 8D shows.
19 Depending on the scale of the antenna assemblies, the
20 apparatus may be highly portable for applications, such
21 as Figs 8B and 8C illustrate. Fig 8B shows a portable
22 device suitable for operation on land whereas Fig 8C
23 shows a portable device suitable for submerged
24 operation by a diver.

25
26 Fig. 9 illustrates how a transmitting antenna assembly
27 201 and a receiving antenna assembly 202 may be
28 arranged in parallel along a tong 250 forming part of a
29 submerged moveable platform 280 which can be attached,
30 for example, to the front of a remotely operated
31 vehicle 260 suitable for operation on a seabed 270.

32

1 Fig 10 illustrates how a plurality of pairs of arrays
2 of transmitting antenna assemblies 201 and receiving
3 antenna assemblies 202 may be arranged on the underside
4 of pontoon-type supports 300a, 300b for use with a
5 semi-submersible platform or sea-vehicle. Such a
6 configuration of the radar apparatus enables sea-bed
7 sensing, imaging and typecasting of materials for the
8 oil industry.

9
10 The antenna pairs are spaced along the pontoon,
11 preferably equidistant from adjacent antenna pairs in
12 the array. At least one array of receiving antennas is
13 arranged parallel to the corresponding array of paired
14 transmitting antennas to enable wide angle reflection
15 and refraction (WARR) sounding. At least one such
16 antenna pair array 310a,310b and 320a,320b is provided
17 on each pontoon, for example, two per pontoon are
18 illustrated in Fig. 10, to form a total of eight arrays
19 of antenna assemblies. Using this apparatus, a
20 variety of large scale structural and compositional
21 information may be collated from and within the seabed,
22 for example, the apparatus may be used in such a
23 "searching mode" to detect subterranean and seabed
24 features.

25
26 The inventor has detected shipwrecks and the apparatus
27 may be suitable for the detection of oil and gas
28 deposits using this apparatus. Features such as
29 shipwrecks may be buried deep below the seabed.
30 Although it is possible to detect such features with a
31 single pair of antenna assemblies over a relatively
32 small search area, an array of antennas, and preferably

1 a multiple array of antennas can be used. Multiple
2 arrays could scan many lines in one forward sweep
3 covering a large search area in a short space of time.

4
5 Furthermore, by allowing the apparatus to remain in
6 situ and scan a fixed area for a period of time, (i.e.
7 to "stare" in the surveying mode) it is possible to
8 record a series of images indicating movement of
9 substances such as liquids (e.g. oil) and gases (e.g.,
10 natural gas seepage).

11
12 In the WARR configuration illustrated in Fig 10, the
13 arrays provided operate in tandem. For example, the
14 transmitting array 310a will emit signals which are
15 reflected and recorded by the receiving array 320b, and
16 the transmitting array 320a will emit signals which are
17 preferably recorded by the receiving array 310b, etc.
18 This enables a plurality of lines 330 to be scanned
19 efficiently along the sea-bed. In the illustrated
20 example, nine lines 330 can be scanned. In WARR mode
21 any antenna assembly can be selected as a transmitter
22 and reflections can be received from any receiving
23 antenna in any specific order and sampling time to
24 allow increasing Tx and Rx (see Fig. 10) separation for
25 triangulation and precision mapping purposes. If this
26 triangulation procedure is carried out, then a detailed
27 table of dielectric properties can be produced
28 including depths, radar velocities, interlayer
29 thicknesses, interlayer velocities, and interlayer
30 dielectric constants.

31

1 The sizes of the apertures of the antenna assemblies
2 may be optimised to suit the path length and the beam
3 collimation requirements. For deeper sounding and
4 longer path lengths it may be necessary to vary the
5 focusing means, for example by fitting narrow apertures
6 with a range of optional circular slits. These can
7 then be fitted to the telescopes to provide focusing at
8 the optimum near/far field ranges. Dielectric lens
9 attachments such as those illustrated in Figs. 5B to 5D
10 may also be used for these purposes. The focusing
11 means selection criteria follows that known in the art
12 from radar design and selection procedures and are
13 based on simple geometric, timing and platform speed
14 considerations.

15
16 For field operation, typical land vehicles include
17 ATVs, small robotic platforms, man-portable and/or hand
18 operated or track or rail mounted for tunnels or mines,
19 or man portable operated from raised bucket platforms
20 for scanning vertical wall surfaces of buildings,
21 tunnels or bridge structures. Typical sea-vehicles
22 include inflatables, hovercraft, Dory work boats, tug-
23 boats, hydrographic/seismic-type survey vessels, or
24 oil-industry semi-submersible platforms with pontoons
25 suitable for mounting large tube-arrays, or ROVs, or
26 autonomous underwater vehicles (AUVs), or Jack-Up
27 Platforms or Drilling Rigs or Stand-Alone Production
28 Platforms. The antenna assemblies are typically
29 arranged substantially vertically and are orientated so
30 that they can stare into the ground/seabed, at depths
31 capable of resolving oil and gas reservoir structures.
32 In a specific example for detecting sub-seabed

1 substances, the antenna assemblies 201, 202 may be of
2 the order of 24m long by 8 inches internal diameter and
3 may comprise two 12m long by 8 inch (internal diameter)
4 high quality steel oil tube casings welded to another
5 two 12m by 8 inch casings to make a pair of large
6 transmitting and receiving assemblies some 24m long.
7 Such a geometry for the antenna assemblies is believed
8 by the inventor to have a natural resonance which
9 amplifies the radar signal by a factor of 180.

10

11 The apparatus may be further mounted on air/space
12 vehicles, for example, small helicopters or remotely
13 powered vehicles (RPVs) such as model aircraft, or
14 balloons, blimps or piloted auto-gyros. Spaceborne
15 platforms may be used for subsurface geological
16 investigations of moons, comets and/or other planets.

17

18 The selection of appropriate antenna configurations and
19 aperture sizes enables different scales to be resolved,
20 for example, objects/substances which are underground
21 or underwater (see for example, Figs 8C, 8D, 9 and 10).

22

23 Fig. 11A illustrates a further embodiment of the
24 invention with a Tx antenna assembly 201 and an Rx
25 antenna assembly mounted on a conventional optical
26 microscope 700, for the purpose of examining, for
27 example, biological samples mounted on microscope
28 slides 702. The Rx assembly 202 is mounted in a socket
29 of the microscope which would normally be occupied by
30 an ocular (eyepiece). The end of the Rx assembly 202
31 may be suitably configured to fit this existing socket.
32 The Tx assembly 201 in this example is mounted in a

1 socket or the like which would normally receive a light
2 source for illuminating the slide 712. If the
3 microscope is of the binocular type, the other ocular
4 may be used for visual observation of the slide and for
5 focussing the microscope. The transmitted signal from
6 the Tx assembly 201 follows the normal optical path
7 through the microscope to the Rx assembly 202. That
8 is, the Tx and Rx assemblies 201, 202 are arranged for
9 transillumination of the slide 702. Alternatively, the
10 Tx and Rx assemblies could be mounted side by side in
11 the ocular sockets of a binocular microscope, for
12 reflection mode operation. In this way, a variety of
13 different types of optical microscope may be adapted
14 for operation as "radar microscopes" and may be used
15 for imaging and/or typecasting of biological samples or
16 the like in a variety of applications including medical
17 diagnosis. For scanning purposes, the slide 702 may be
18 translated relative to the Tx and Rx assemblies by
19 using the conventional movable slide stage of the
20 microscope.

21
22 For precision mapping applications of the invention, it
23 is necessary to employ calibrated antenna assemblies,
24 preferably of the type illustrated in Figs. 5E to 5N,
25 whose relative separation can be varied for optimised
26 triangulation of range distance. Preferably, the
27 transmitting, Tx, and receiving antennas, Rx, can be
28 rotated about their longitudinal axes through $0 - 360^\circ$
29 relative to one another to enable variable polarisation
30 of signals, so as to optimise coherent image
31 reflections of targets and interfaces of interest.

32

1 The triangulation factor is important for many
2 applications of the invention. The polarisation factor
3 is of greatest significance for close range inspection
4 of structures such as pipes or concrete sections.
5 Changing the polarisation, by a factor of 90° for
6 example, can enable the collection of multivariate
7 image-data sets along each scan line. This often
8 assists the classification of the medium and provides
9 co-ordinates of point targets or structures in the
10 medium being investigated.

11
12 The antennas can typically be oriented in two ways:
13 plane polarised (PP or Plane Mode) or cross polarised
14 (CP, 90° mode) where Tx is oriented at 90° to Rx or vice
15 versa. Therefore, at any given frequency, two
16 different sets of spectral reflection data (or digital
17 image bands) can be collected. The design of suitable
18 spatial frequency filters and the use of principal
19 components analysis (PCA) for multivariate image
20 mapping of such complex multi-spectral and multi-
21 polarised image datasets can greatly assist in
22 identifying, for example, engineering structures of
23 interest for precision mapping and classification.

24
25 Consideration must also be given to the spatial (X,Y,Z)
26 co-ordinates of both the transmitting and receiving
27 antennas. This means that the area to be investigated
28 should be precisely surveyed to build up a concise
29 topographic survey database of co-ordinates for each
30 line scanned. In cases where the scanning lines are
31 non-linear, it is important to track the antennas on

1 their scanning platform during the data collection
2 phase.

3
4 This situation may arise, for example, when scanning
5 the irregular topographic features of a biopsy
6 specimen, as the antennas will be mounted on a simple
7 biopsy scanning platform (BSP) and not in direct
8 contact with the surgical specimen. With a fixed
9 antenna configuration on a BSP, where the tissue is
10 irregular, the air gap between the antenna and the
11 specimen will vary considerably. Therefore, it is
12 important to simultaneously track the antennas during
13 the scanning phase so that the true subject datum plane
14 is known and can be related to precise X, Y and Z co-
15 ordinates of the subject being investigated.

16
17 To achieve coherent imaging, it is important that the
18 optimum scan configuration of the antennas is selected.
19 Essentially, this is the fixed separation distance
20 between the Tx and Rx antennas mounted on the scanning
21 rig or BSP. For imaging of deeper structures the
22 antennas have to be fixed with a wider separation
23 distance. Again, for focussing through lower
24 dielectric materials or deeper organs in the body, the
25 antennas should be moved further apart. To acquire
26 accurate depth data it is important to triangulate
27 every scan line, in the body's sub-surface domain.
28 This can be achieved by overlapping scan legs from the
29 start of scan position (SOS) to the end of scan
30 position (EOS). This type of scanning is commonly
31 referred to as a WARR scan (wide angle reflection and
32 refraction, as illustrated in Fig. 11A which shows a

1 fixed Tx antenna assembly 201, and a movable Rx antenna
2 assembly 202 moving progressively away from the Tx
3 antenna 201 in the direction of the arrows, relative to
4 a subject 704, such as a cancer tumour within a body).
5 This can be achieved by automatic sensor array digital
6 switching, managed by software control.

7

8 As the scanning rig moves along the scan line, the Rx
9 antenna assembly captures each new reflection and plots
10 the returns alongside the previously scanned returns.
11 This process integrates reflection traces and
12 eventually a comprehensive image of the subject 704 is
13 obtained. To compose a coherent image, the system
14 processes the response reflections from the objects
15 examined. These are automatically enhanced to optimise
16 desired targets and layered boundary reflections may be
17 classified.

18

19 The images may also be suitably scaled by software,
20 with re-sampling and auto-zoom features enabling 2-D
21 and 3-D visualisation of point targets and boundary
22 interfaces, displayed in real time. These features,
23 together with the use of classified colour palettes,
24 can discriminate the textural classes or surface
25 roughness (for example) of a wide range of materials.
26 A typical breast carcinoma may consist of six distinct
27 tissue layers, with layer thicknesses measured in
28 micrometers (e.g.: 76, 76, 152, 202, 88, 77), each with
29 a different dielectric constant.

30

31 Further analysis of the image may display dielectric
32 tables showing mean inter-layer thicknesses, depths,

1 propagation velocities and dielectric constants. These
2 tables may also include RMS error computations in two
3 way travel time measured in nanoseconds (NS) and depth
4 in metres (m) for each stratigraphic boundary.

5

6 The preferred signal processing software performs real-
7 time de-convolution of the transmit pulse to allow true
8 conformal mapping of object shapes. For example,
9 conventional GPR reflections from circular or
10 elliptical section structures such as pipes occur as
11 parabolic echoes from the top and bottom of the pipe
12 reflecting surfaces, whereas mapping in the manner
13 described above will display the structures in their
14 true circular or elliptical shapes.

15

16 From the resultant images, materials can be
17 spectroscopically identified and classified (as
18 described further below), provided they have been
19 previously typecasted and their spectral
20 characteristics logged in the reference database. If
21 this is the case, classification is possible in near-
22 real-time; that is, within a few micro-seconds of data
23 capture. Depths can be automatically calculated by the
24 system computer after the WARR results have been
25 implemented. Thus, it is simply a matter of reading
26 the depth of a required target position from the scaled
27 image.

28

29 Fig. 12 is a table summarising system specifications
30 for a variety of operational modes of systems embodying
31 the invention. Fifteen modes of operation A1 - A5, B1
32 - B5 and C1 - C5 are indicated, exemplifying the broad

1 range of applications of the invention. Modes A1 - A5
2 are close range/near field (small scale) modes for a
3 range of increasing distances between the Tx antenna
4 and the subject, suitable for applications such as
5 biological and medical imaging. Modes B1 - B5 are near
6 to medium range (medium scale) modes, again for a range
7 of increasing distances, suitable for typical GPR
8 applications with relatively shallow penetration.
9 Modes C1 - C5 are long range (large scale) modes,
10 suitable for geological/geophysical applications,
11 particularly in the oil industry, for relatively deep
12 subsea/subsurface penetration. The various modes would
13 typically use substantially the same computer, pulse
14 generator and radar control apparatus, with different
15 Tx and Rx antenna assemblies, these preferably being of
16 the types illustrated in Figs. 5A to 5N, smaller
17 assemblies (e.g. about 200 mm to 300 mm in length)
18 being used for modes A1 to A5, intermediate size
19 assemblies being used for modes B1 to B5, and larger
20 size assemblies (e.g. up to about 24 m in length) being
21 used for modes C1 to C5.

22
23 The resolution time and resolution space (columns 2 and
24 3) indicate the resolution which may be obtained using
25 each mode. Values given are for salt water and may be
26 converted for other media with different dielectric
27 properties. Column 4 indicates suitable values of the
28 Pulse Repetition Frequency (PRF) for each mode, being
29 higher for close range applications and lower for
30 longer range applications. Column 4 indicates suitable
31 Pulse Width (Pw) values for the various modes, these
32 being shorter for close range modes and longer for long

1 range modes. For each of modes A1 - A5, suitable
2 values are in the range 10 - 100 ps (picoseconds) i.e.
3 0.01 to 0.1 ns (nanoseconds); for each of modes B1 -
4 B5, suitable values are in the range 1 - 10 ns; for
5 each of modes C1 - C5, suitable values are in the range
6 10 to 25 ns. The table of Fig. 12 utilises Pw values
7 of 0.1 ns for modes A1 - A5, 1 ns for modes B1 - B5 and
8 10 ns for modes C1 - C5. Column 6 indicates the Time
9 Range (TR) in the received signal produced by each
10 transmitted pulse which will contain data of interest
11 at the relevant distance and scale. The Time Range
12 would normally begin with the first peak of the
13 received signal. The Time Range is shorter for close
14 range/small scale applications and longer for long
15 range/large scale applications.

16
17 Columns 6 and 7 indicate the preferred frequency ranges
18 (Fmin to Fmax) of the transmitted pulse for each mode,
19 being higher for close range/small scale applications
20 requiring little penetration and high resolution and
21 lower for long range/large scale applications requiring
22 deep penetration and lower resolution. The frequency
23 range is determined by the radar system as a whole,
24 including the characteristics of the TX and Rx
25 antennas. Columns 9 to 11 indicate suitable values of
26 pulses-per-trace (Ptr), scan rate (SR, traces-per-
27 second) and Sdelay (1/SR) for the purposes of sampling,
28 storing and displaying digitised data.

29

30 The total frequency range of the radar systems is
31 indicated as 1 MHz to 10 GHz, which covers an
32 exceptionally wide range of frequencies. This range is

1 suited for the various imaging and typecasting
2 operations of the apparatus at various distances and
3 scales. For each of the fifteen modes, the sampling
4 rate (F_s) most preferably equals two times the maximum
5 frequency (F_{max}) as indicated in column 7 of Fig. 12B.
6 The sampling rate is determined by the difference in
7 time delays from pulse to pulse. For all modes of
8 operation, the sampling rate preferably falls in the
9 range $F_{max}/4$ to $4F_{max}$. The sampling time, T_s (column
10 12), is different from the sampling rate, being the
11 time during which the analogue signal is sampled before
12 being digitised, corresponding to the time represented
13 by one pixel in the y-direction. Preferably, on
14 average, the sampling time T_s is $1/(2F_{max})$. It should
15 be at least $1/F_{max}$ but for fast scanning it is
16 recommended to be $1/(4F_{max})$ which equates to 0.25 ns
17 where $F_{max} = 1$ GHz.

18
19 It is important that the analogue input signal is
20 filtered before sampling to avoid aliasing. This is
21 partially accomplished by the sampler 516 (Fig. 2)
22 which averages the signal over the sampling time. The
23 lower frequency range is limited by the Tx and Rx
24 antennas, the time window and a low frequency component
25 from the radar. The lowest frequency that can be
26 resolved is the reciprocal of the time from time zero
27 to the end of the trace. For example, consider mode A5
28 of Fig. 12. In this case, the 25 ns time range (column
29 6) will have a minimum frequency of $(25 \text{ ns})^{-1}$, i.e. 40
30 MHz. This is an absolute minimum value. For practical
31 purposes, a higher value (100 MHz in Fig. 12) is
32 preferably selected.

1
2 Modes A1 to A5 are intended for close range or near
3 field imaging and typecasting such as in medical and
4 biological applications. The recommended frequency
5 ranges for these modes of operation is from a minimum
6 frequency (F_{min}) in the range 100 MHz (A5) to 1 GHz
7 (A1) to a maximum frequency in the range 1 GHz (A5) to
8 10 GHz (A1). For these frequency ranges, the sampling
9 rate (F_s) is determined by the difference in time
10 delays from pulse to pulse. As noted above, the
11 criterion for selecting F_s is that it should be at
12 least two times F_{max} for most applications, or
13 preferably four times F_{max} for some specific
14 applications such as fast scanning. The preferred
15 overall range for all modes is $F_{max}/4$ to $4F_{max}$.

16
17 The pulse repetition frequency (PRF) is the rate at
18 which pulses are emitted from the transmitter. For
19 close range (focussed near field imaging) medical and
20 biological applications, PRF should be at least 64 kHz
21 for combined imaging and typecasting applications, but
22 the preferred maximum value is 100 kHz.

23
24 The number of pulses per trace (P_{tr} , column 9, Fig.
25 12B) is important for efficient operation of the
26 apparatus. The preferred maximum P_{tr} for modes A1 -
27 A5, to cover a wide range of diagnostic medical,
28 biological and biochemical applications, is 100 pulses
29 per trace. The maximum time window, T_R , is a function
30 P_{tr} and T_s , as follows: $T_R = (P_{tr} \times T_s)$. Accordingly,
31 in mode A3 operation: $T_s = 1/2F_{max}$; i.e. $T_s = 10^{-10} =$
32 0.1 ns; $T_R = (100 \times 0.1) \text{ ns} = 10 \text{ ns}$.

1

2 There is a trade off between parameters for optimum
3 imaging and typecasting performance. Higher values of
4 Fmax always give better results in terms of resolution
5 etc. but at the expense of penetration, data processing
6 etc.

7

8 Modes B1 - B5 relate to near range to medium range
9 (focused subsurface imaging) general ground penetrating
10 radar (GPR) applications. For these modes, the
11 preferred value of PRF is also 100 kHz. The optimum
12 range of Ptr to cover this range of applications is
13 4000 to 9600 pulses per trace.

14

15 Modes C1 - C5 relate to medium range to long range (far
16 field) applications. For many far field geological
17 applications, a most appropriate time range would be of
18 the order of 20000 to 80000 ns. For deep geological
19 applications (i.e. shallow seismic to deep seismic type
20 depths up to thousands of metres), the time ranges of
21 the order of 160000 to 250000 ns may be selected.

22

23 Stacking the pulse (St) is a common method of enhancing
24 the imaged products in conventional geophysical or
25 seismic imaging. This technique can be applied in the
26 present system at the time of data collection (through
27 digital control) or it can be carried out externally by
28 post-processing of the collected radar imagery. In the
29 latter case, then the data collection rate is
30 preferably increased.

31

1 The scanning rate (SR) equals the number of traces (or
2 scans) per second. The maximum value of SR equals PRF
3 divided by the product of Ptr and St. For example
4 (mode A1), where Ptr equals 40, PRF equals 100 kHz and
5 St equals 1 (no stacking), then $SR = (100 \times 10^3) / (40 \times$
6 $1) = 2500$ scans per second.

7
8 With reference to the setting up of the radar system
9 for operational use, the time zero (T_0) position is of
10 particular importance. T_0 will generally be selected as
11 appropriate for a particular application, to ensure
12 that all of the relevant received signal data is
13 retrieved. In general terms T_0 is the time at which the
14 transmitted pulse is received by the shortest
15 transmission path between the transmitter and the
16 receiver (the "direct wave", e.g. transmitted through
17 air in an air medium or through water in a water
18 medium). The required T_0 position is not actually the
19 zero point on the time scale because the pulse has
20 travelled from the transmitter unit to the receiver
21 unit, so the T_0 position actually corresponds to the
22 distance between the transmitter antenna and the
23 receiver antenna divided by the speed of the pulse.
24 This factor is important for obtaining accurate depth
25 measurements through materials, especially those with
26 multivariate dielectric constants and inter-layer
27 velocities. It is important that the T_0 position is
28 included in the time window range (TR, column 6, Fig.
29 12) or in the displayed image on the visual display
30 unit of the computer. The direct wave received pulse
31 can be used to de-convolve the image. This will
32 generally produce a less cluttered image; i.e. objects

1 such as circular section pipes will appear circular
2 rather than as parabolic reflections of the top and
3 bottom of the pipe.

4
5 The position of T_0 in the image depends on the various
6 delays in the radar system and is preferably set up
7 when the radar is first switched on, before any other
8 settings are altered.

9
10 The foregoing discussion, referring to Fig. 12 of the
11 drawings, applies particularly to transillumination and
12 reflection modes of operation.

13
14 To set up appropriate conditions in order to typecast
15 material in chamber mode operation (as illustrated in
16 Fig. 6A), the following technique may be used when
17 using a conventional GPR radar set (or equivalent) as
18 the pulse generator. To provide optimum control during
19 the set up procedure, the best method found by the
20 inventor is to switch off the Automatic Gain Control
21 and the Time Varying Gain Control of the pulse
22 generator 21 (Fig. 1). A reasonable received signal
23 bandwidth is then established by suitable selection of
24 the cut-off frequencies of a high-pass filter and low-
25 pass filter; for example, between 40 Hz and 3.2 kHz.

26
27 A large enough time window is selected for sampling to
28 allow a sufficient number of resonant ringing
29 reflections through the scanned substance/object to
30 have occurred to enable significant spectral
31 relationships for each sampled substance to be
32 established. The inventor has found that in the case

1 where a 25ml sample was placed in the chamber portion
2 4a (Fig. 6A), and 20ml of air was left in the sample
3 chamber portion 4b, that a suitable time window was
4 approximately 16ns. Increasing the minimum time window
5 to, for example, 25ns, further enables sufficient
6 resonant effects to be established and tested. The
7 sampling interval, or scan rate, is selected to allow a
8 sufficient pulse dwell time to enable resonance through
9 the sampled substance to be optimised. In this
10 example, sampling was optimised with a sampling
11 interval of 100ms (10 scans per second) to ensure that
12 consistent results were obtained on repetitive tests.
13 In general, as a lower limit, the sampling interval
14 should not be less than 50ms; i.e. the scan rate should
15 not exceed 20 scans per second. However, for certain
16 fast scanning applications, it is possible to scan at
17 200 scans per second and it is also possible for
18 typecasting to be performed at this rate.

19
20 The data obtained using the apparatus, systems and
21 methods as described thus far may be used for a variety
22 of purposes, including imaging, mapping, dimensional
23 measurement, and typecasting (identification of
24 materials etc.).

25
26 The time domain data as received by the receiver may be
27 processed for imaging/mapping/measurement purposes
28 using well known techniques employed in conventional
29 GPR and other imaging/mapping applications, which will
30 not be described herein.

31

1 The time domain data may be transformed into frequency
2 domain data, by means of Fourier Transform techniques
3 (especially FFT). This provides an energy/frequency
4 spectrum which, in accordance with one aspect of the
5 invention, may be used as a unique signature to
6 identify (typecast) the material which produced the
7 spectrum. In accordance with this aspect of the
8 invention, the energy/frequency spectrum is analysed
9 using any of a variety of well known statistical
10 analysis methods (such as principal components
11 analysis, maximum likelihood classification or
12 multivariate classification) or combinations of such
13 methods, in order to obtain a parameter set. A
14 reference database of known materials is established,
15 comprising the original time domain data, and/or the
16 transformed data, and/or the parameter set obtained
17 therefrom, and an unknown material can thereafter be
18 identified by comparing its parameter set, also
19 obtained by means of the apparatus, systems and methods
20 of the present invention, with those in the reference
21 database. The statistical analysis of the
22 energy/frequency spectrum may be performed either by
23 frequency classification (using energy bins) or by
24 energy classification (using frequency bins).
25
26 Conventional analytical methods may also be applied to
27 the data for classification purposes, such as time
28 domain reflectrometry techniques, velocity distribution
29 analysis or the like, as used in conventional
30 geophysical applications for determining dielectric
31 properties.
32

1 The computer forming part of the radar system in
2 accordance with the invention may be programmed to
3 perform these functions.

4
5 By use of the invention, it is possible to classify and
6 map oil, water and gas reserves deep underground
7 without the need for drilling. By staring deep
8 underground, it is possible to monitor oil, water and
9 gas movements and to classify oils already typecast and
10 held in reference databases of oil types etc.

11
12 Other applications include the detection of explosives,
13 contraband substances, and in particular narcotics, as
14 well as the typecasting of rock, soil, sediment and ice
15 cores, and biological/medical imaging and diagnosis.

16
17 The preferred antenna assemblies of the present
18 invention (Figs. 5A to 5N) are believed to operate in a
19 manner analogous to a laser, except that radio waves
20 are resonated in a highly dielectric medium and with a
21 carefully selected dielectric medium and with a
22 carefully selected dielectric lens aperture with
23 concentric circular focusing slits. With a 3mm
24 aperture, it is possible to focus the beam from 3mm
25 outside the central aperture to infinity, like a pin-
26 hole camera.

27
28 An example image obtained by means of the invention is
29 shown in Fig 11. The image represents a scan of a
30 short cylindrical core of gold in a quartzite seam
31 indicated at A. The width of this short scanned

1 portion is 280mm and the diameter of the gold core is
2 approximately 40mm.

3

4 The vertical dimension reflects the time domain and the
5 horizontal scale has been rectified to represent the
6 length of the core scanned by the moving antenna pair.

7 The top of the image is 0ns. Further time delays
8 represent signals reflected from deeper within the
9 sample core. Looking down through the core reflections

10 are recorded to about 5.4ns. Two further harmonic
11 reflections are provided which provide information on
12 surface roughness of the core and arise from too much
13 initial power being used to generate the radar pulse.

14 The first reflection lies from approximately 7ns to
15 13ns in time range and the second multiple surface
16 reflection shows an enlarged portion of the core from
17 17ns to 25ns, the limit of the 25ns time window
18 selected.

19

20 The selection of appropriate circular slit apertures
21 224, 225 and ring spacings 226 and the choice of
22 dielectric filler 228 which launches the wave enables
23 the internal structure of the core to be perceived. If
24 the anode length is proportional to the tube length as
25 previously described, for example $1/\alpha$ or in this case
26 $1/10$ th of the total internal telescope tube 227 length,
27 then the time delay of the radar beam (i.e., the time
28 from emission to detection) is multiplied by the
29 reciprocal α of the fraction $1/\alpha$; i.e., the actual time
30 delay $T_D = \alpha \times$ the expected time delay T_E , where T_E is
31 as is given in conventional ground penetrating radar

1 (GPR) formulae. Using the conventional GPR Range
2 Formulae, this 40 mm core of quartzite with a mean
3 dielectric constant ($\epsilon_R = 5$) should have produced an
4 equivalent time range length on the image of 0.54ns,
5 but the 10:1 factor stretched the time range because
6 the beam was slowed down in the telescope and this
7 resulted in a time range image spanning 5.4ns. This is
8 considered by the inventor to be a tube geometry and
9 dielectric lens effect, and will assist in the near
10 range focusing of radio-wave cameras and microscopes as
11 well as radio-wave telescopes for mapping deep below
12 ground level or the sea-bed.

13
14 The above description relates to particular embodiments
15 of the invention. In general, the values or ranges of
16 values indicated for various parameters may all vary
17 and may be dependent on the particular application of
18 the invention.

19
20 Furthermore, if the dielectric properties of the
21 cladding material surrounding the antenna of the
22 telescopes vary under given conditions, for example if
23 the dielectric constant is thermally dependent, such as
24 is the case with barium titanate, then it is possible
25 to detect such conditions by using the invention to
26 "stare" at the substance and monitoring the change in
27 the received spectral data. This could enable the
28 thermal conditions of subterranean
29 structures/substances/objects to be determined. Other
30 dielectrics of interest include lead zirconate titanate
31 (PZT) and ammonium dihydrogen phosphate.

1
2 For the removal of doubt, wherever specific reference
3 has been made to a "substance", "sample" or the like,
4 the term may be taken to include other objects, liquids
5 and powders as well as larger or smaller scale
6 geological, marine or biological features etc. The
7 term "subject" as used herein means any such substance,
8 sample, object, feature etc. to be imaged, detected or
9 analysed by means of the invention.

10
11 It will be understood that for certain applications of
12 the invention, the transmitting and receiving antennas,
13 antenna arrays or antenna assemblies may be combined in
14 transceiver arrays or assemblies.

15
16 While several embodiments of the present invention have
17 been described and illustrated, it will be apparent to
18 those skilled in the art once given this disclosure
19 that various modifications, changes, improvements and
20 variations may be made without departing from the
21 spirit or scope of this invention.

1 Claims

2

3 1. A radar antenna assembly for use as a transmitter,
4 receiver or transceiver comprising:

5 a tubular casing having a radar-reflective inner
6 surface and having a first end, a second end and a
7 longitudinal axis;

8 a radar-reflective reflector closing said first
9 end;

10 an aperture disposed at said second end;

11 at least one elongate antenna element extending
12 substantially parallel to said longitudinal axis from
13 said reflector towards said second end; and

14 dielectric material substantially filling the
15 interior volume of said tubular casing.

16

17 2. A radar antenna assembly as claimed in Claim 1,
18 further including focussing means at said second end.

19

20 3. A radar antenna assembly as claimed in Claim 2,
21 wherein said focussing means includes a plurality of
22 concentric slit ring apertures located at said second
23 end.

24

25 4. A radar antenna assembly as claimed in Claim 2 or
26 Claim 3, wherein said focussing means includes at least
27 one dielectric lens element located at said second end.

28

29 5. A radar antenna assembly as claimed in Claim 4,
30 wherein said dielectric lens element comprises a planar
31 lens element.

32

1 6. A radar antenna assembly as claimed in Claim 4,
2 wherein said dielectric lens element comprises a plano-
3 concave lens element.

4

5 7. A radar antenna assembly as claimed in Claim 4,
6 wherein said dielectric lens element comprises a plano-
7 convex lens element.

8

9 8. A radar antenna assembly as claimed in any
10 preceding Claim, wherein said tubular casing has an
11 inner diameter D_T of which is an integer multiple of the
12 diameter D_A of said at least one antenna element.

13

14 9. A radar antenna assembly as claimed in any
15 preceding Claim, wherein said tubular casing has an
16 interior length L_T which is an integer multiple of the
17 length L_A of said at least one antenna element.

18

19 10. A radar antenna assembly as claimed in any
20 preceding Claim, wherein an interior surface of said
21 tubular casing comprises an antenna cathode and said
22 elongate antenna element comprises an antenna anode.

23

24 11. A radar antenna assembly as claimed in Claim 10,
25 wherein said elongate antenna element extends along
26 said longitudinal axis.

27

28 12. A radar antenna assembly as claimed in any one of
29 Claims 1 to 9, including at least two of said elongate
30 antenna elements, at least one of which comprises an
31 antenna cathode and at least one of which comprises an
32 antenna anode.

1

2 13. A radar antenna assembly as claimed in Claim 12,
3 wherein said elongate antenna elements are disposed
4 symmetrically about the longitudinal axis of the
5 tubular casing.

6

7 14. A radar antenna assembly as claimed in Claim 13,
8 wherein said elongate antenna elements have
9 substantially equal lengths and diameters.

10

11 15. A radar antenna assembly as claimed in Claim 14,
12 wherein the interior diameter D_T of the tubular casing
13 is an integer multiple of the diameter D_A of said
14 elongate antenna elements and of the spacing between
15 adjacent pairs of said elongate antenna elements.

16

17 16. A radar antenna assembly as claimed in any
18 preceding Claim, wherein said dielectric material is a
19 liquid.

20

21 17. A radar antenna assembly as claimed in any
22 preceding Claim, wherein said dielectric material is a
23 solid.

24

25 18. A radar antenna assembly as claimed in any
26 preceding Claim, wherein said dielectric material is a
27 powdered solid packed into the interior of said tubular
28 casing.

29

30 19. A radar antenna assembly comprising a closed
31 chamber adapted to contain a sample of material, said
32 chamber including four substantially triangular side

1 walls together defining an open-based pyramidal
2 structure, said assembly including transmitter antenna
3 elements disposed on interior surfaces of a first
4 opposed pair of said triangular side walls and receiver
5 antenna elements disposed on interior surfaces of a
6 second opposed pair of said triangular side walls.

7
8 20. A radar antenna assembly as claimed in Claim 19,
9 wherein said antenna elements comprise bowtie dipole
10 antennas with respective cathode and anode elements
11 disposed on said opposed pairs of said triangular side
12 walls.

13
14 21. A radar antenna apparatus as claimed in Claim 19
15 or Claim 20, wherein the base of said pyramidal
16 structure is closed by a generally planar base wall,
17 said chamber comprising the interior volume of said
18 pyramidal structure.

19
20 22. A radar antenna assembly as claimed in Claim 19 or
21 Claim 20, wherein said chamber comprises a closed
22 volume communicating with the open base of said
23 pyramidal structure.

24
25 23. A radar system comprising pulsed signal generating
26 means, transmitter antenna means, receiver antenna
27 means, control means for controlling the operation of
28 said pulsed signal generating means, analog-digital
29 converter means for digitising signals received by said
30 receiver antenna means, and data storage means for
31 storing said digitised signals, wherein said
32 transmitter antenna means and receiver antenna means

1 comprise at least one radar antenna assembly as claimed
2 in any one of Claims 1 to 22.

3

4 24. A radar system as claimed in Claim 23, wherein
5 said transmitter antenna means comprises at least one
6 transmitter radar antenna assembly as claimed in any
7 one of Claims 1 to 18, and said receiver antenna means
8 comprises at least one receiver radar antenna assembly
9 as claimed in any one of Claims 1 to 19.

10

11 25. A radar system as claimed in Claim 24, wherein
12 said transmitter and receiver antenna assemblies are
13 disposed so as to transilluminate a subject.

14

15 26. A radar system as claimed in Claim 24, wherein
16 said transmitter and receiver antenna assemblies are
17 disposed so as to be co-axially aligned on opposite
18 sides of a subject.

19

20 27. A radar system as claimed in any one of Claims 24
21 to 26, wherein said transmitter and receiver antenna
22 assemblies are connected to a closed sample chamber
23 adapted to enclose a subject.

24

25 28. A radar system as claimed in Claim 24, wherein
26 said transmitter and receiver antenna assemblies are
27 disposed such that said receiver antenna assembly
28 receives a signal transmitted by said transmitter
29 antenna assembly and reflected from a subject.

30

31 29. A radar system as claimed in Claim 28, wherein
32 said transmitter and receiver antenna assemblies are

1 arranged such that their longitudinal axes are
2 substantially parallel to one another with their second
3 ends facing in the same direction.
4

5 30. A radar system as claimed in Claim 28 or 29,
6 wherein said system is adapted to be portable.
7

8 31. A radar system as claimed in Claim 28 or Claim 29,
9 wherein said system is adapted to be carried by a land
10 vehicle.
11

12 32. A radar system as claimed in Claim 28 or Claim 29,
13 wherein said system is adapted to be carried by a
14 water-borne vessel.
15

16 33. A radar system as claimed in Claim 28 or Claim 29,
17 wherein said system is adapted to be carried by a
18 submersible vehicle.
19

20 34. A radar system as claimed in Claim 28 or Claim 29,
21 wherein said system is adapted to be carried by an
22 airborne vehicle.
23

24 35. A radar system as claimed in Claim 28 or 29,
25 wherein said system is adapted to be carried by a space
26 vehicle.
27

28 36. A radar system as claimed in Claim 28 or Claim 29,
29 wherein the position of said transmitter antenna
30 assembly is fixed relative to said receiver antenna
31 assembly.
32

1 37. A radar system as claimed in Claim 28 or Claim 29,
2 wherein at least one of said transmitter antenna
3 assembly and said second antenna assembly is adapted to
4 be movable relative to a subject.

5

6 38. A radar system as claimed in Claim 28 or Claim 29
7 in which one of said transmitter and receiver antenna
8 assemblies is adapted to be movable relative to the
9 other.

10

11 39. A radar system as claimed in any one of Claims 28
12 to 38, including a plurality of transmitter antenna
13 assemblies.

14

15 40. A radar system as claimed in any one of Claims 28
16 to 39, including a plurality of receiver antenna
17 assemblies.

18

19 41. A radar system as claimed in any one of Claims 28
20 to 40, for use with close range subjects, in which said
21 control means is adapted to control said pulsed signal
22 generating means so as to generate pulses with a pulse
23 repetition frequency of the order of 100 kHz.

24

25 42. A radar system as claimed in any one of Claims 28
26 to 41, for use with close range subjects, in which said
27 control means is adapted to control said pulsed signal
28 generating means so as to generate pulses with a pulse
29 width in the range 0.01 to 0.1 nanoseconds.

30

1 43. A radar system as claimed in any one of Claims 28
2 to 42, for use with close range subjects, adapted to
3 capture data in a time range of 2 to 25 nanoseconds.
4

5 44. A radar system as claimed in any one of Claims 28
6 to 43, for use with close range subjects, adapted to
7 transmit pulses with a minimum frequency in the range
8 100 to 1000 MHz and with a maximum frequency in the
9 range 1000 to 10000 MHz.
10

11 45. A radar system as claimed in any one of Claims 28
12 to 40, for use with close to medium range subjects, in
13 which said control means is adapted to control said
14 pulsed signal generating means so as to generate pulses
15 with a pulse repetition frequency of the order of 25 to
16 100 kHz.
17

18 46. A radar system as claimed in any one of Claims 28
19 to 40 or 45, for use with close to medium range
20 subjects, in which said control means is adapted to
21 control said pulsed signal generating means so as to
22 generate pulses with a pulse width in the range 1 to 10
23 nanoseconds.
24

25 47. A radar system as claimed in any one of Claims 28
26 to 40, or 45 or 46, for use with close to medium range
27 subjects, adapted to capture data in a time range of
28 2000 to 10000 nanoseconds.
29

30 48. A radar system as claimed in any one of Claims 28
31 to 40, or 45 to 47, for use with close to medium range
32 subjects, adapted to transmit pulses with a minimum

1 frequency in the range 12.5 to 125 MHz and with a
2 maximum frequency in the range 200 to 2000 MHz.

3

4 49. A radar system as claimed in any one of Claims 28
5 to 40, for use with long range subjects, in which said
6 control means is adapted to control said pulsed signal
7 generating means so as to generate pulses with a pulse
8 repetition frequency of the order of 3.125 to 50 kHz.

9

10 50. A radar system as claimed in any one of Claims 28
11 to 40 or 49, for use with long range subjects, in which
12 said control means is adapted to control said pulsed
13 signal generating means so as to generate pulses with a
14 pulse width in the range 10 to 25 nanoseconds.

15

16 51. A radar system as claimed in any one of Claims 28
17 to 40, or 49 or 50, for use with long range subjects,
18 adapted to capture data in a time range of 20000 to
19 250000 nanoseconds.

20

21 52. A radar system as claimed in any one of Claims 28
22 to 40, or 49 to 51, for use with long range subjects,
23 adapted to transmit pulses with a minimum frequency in
24 the range 1 to 12.5 MHz and with a maximum frequency in
25 the range 12.5 to 200 MHz.

26

27 53. A radar system as claimed in any one of Claims 23
28 to 52, further including data processing means for
29 processing said digitised signals.

30

31 54. A radar system as claimed in Claim 53, wherein
32 said data processing means is adapted to process said

1 digitised signals for the purposes of at least one of
2 imaging, measuring, mapping, detecting, identifying and
3 typecasting said subject.

4
5 55. A method of typecasting a subject comprising the
6 steps of:

7 irradiating the subject with a pulsed, broad band
8 radar frequency signal transmitted by at least one
9 transmitter antenna;

10 detecting a return signal following interaction of
11 said transmitted signal with said subject, using at
12 least one receiver antenna;

13 calculating an energy-frequency spectrum of said
14 return signal; and

15 analysing said energy-frequency spectrum to obtain
16 a characteristic energy-frequency signature of said
17 subject.

18
19 56. A method as claimed in Claim 55, wherein said step
20 of analysing said energy-frequency spectrum comprises
21 performing a statistical analysis of said energy
22 frequency spectrum.

23
24 57. A method as claimed in Claim 56, wherein said
25 statistical analysis includes at least one of principal
26 components analysis, maximum likelihood classification
27 and multivariate classification.

28
29 58. A method as claimed in any one of Claims 55 to 57,
30 wherein said step of analysing said energy-frequency
31 spectrum comprises frequency classification using
32 energy bins.

1 59. A method as claimed in any one of Claims 55 to 57,
2 wherein said step of analysing said energy-frequency
3 spectrum comprises energy classification using
4 frequency bins.

5

6 60. A method of identifying an unknown subject
7 comprising the steps of:

8 obtaining an energy-frequency signature of said
9 subject using the method of any one of Claims 55 to 59;
10 and

11 comparing said energy-frequency signature of the
12 unknown subject to a database of energy-frequency
13 signatures of known subjects previously obtained using
14 the method of any one of Claims 55 to 59.

15

16 61. A method as claimed in any one of Claims 55 to 60,
17 implemented using a radar system as claimed in Claim 53
18 or 54.

19

20 62. A radar system as claimed in Claim 53 or 54,
21 wherein said data processing means is adapted to
22 perform the method of any of Claims 55 to 60.

23

24

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
15 March 2001 (15.03.2001)

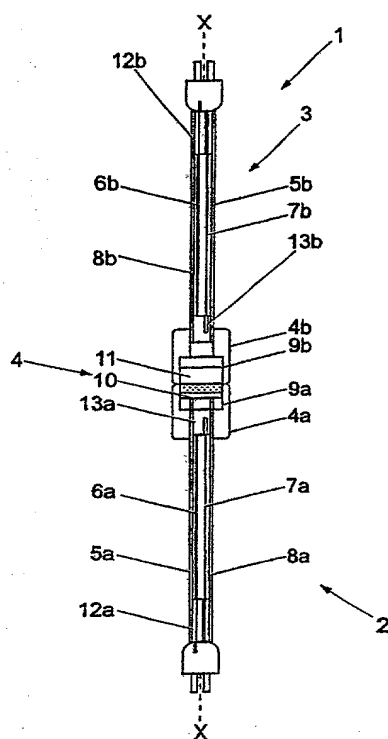
PCT

(10) International Publication Number
WO 01/18533 A1

- (51) International Patent Classification⁷: G01N 22/00 (81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.
- (21) International Application Number: PCT/GB00/03431
- (22) International Filing Date:
7 September 2000 (07.09.2000)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
9921042.9 7 September 1999 (07.09.1999) GB
- (84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).
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Street, Glasgow G5 8QA (GB).
- Published:
— With international search report.
— Before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments.

[Continued on next page]

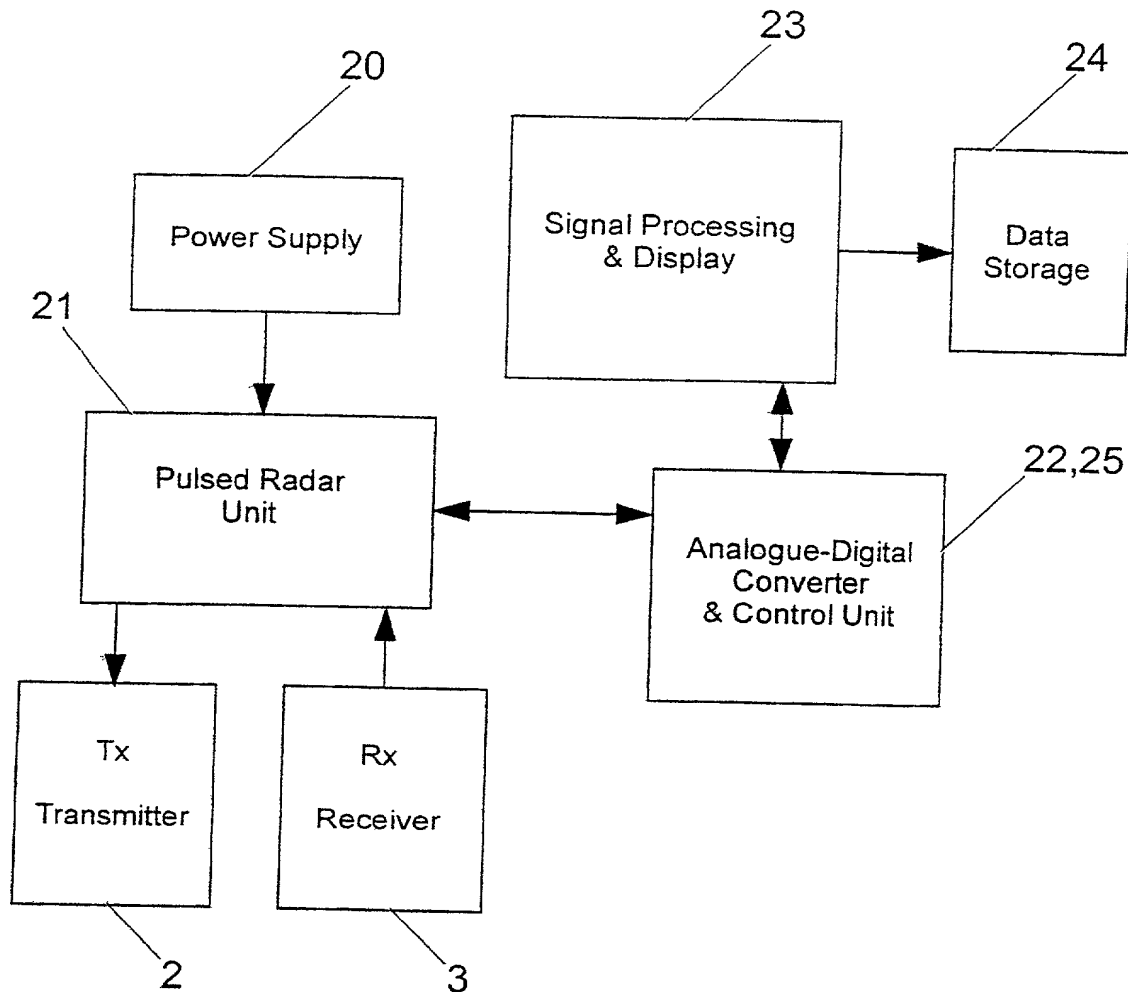
(54) Title: RADAR APPARATUS FOR IMAGING AND/OR SPECTROMETRIC ANALYSIS AND METHODS OF PERFORMING IMAGING AND/OR SPECTROMETRIC ANALYSIS OF A SUBSTANCE FOR DIMENSIONAL MEASUREMENT, IDENTIFICATION AND PRECISION RADAR MAPPING



(57) Abstract: Radar apparatus and methods of use thereof for imaging and/or spectrometric analysis. The invention employs pulsed radar signals for magnifying, imaging, scale measuring, identifying and/or typecasting the composition of substances by radargrammetric imaging and/or statistical analysis of energy/frequency spectrums. The invention may be used to locate and/or distinguish a substance from other substances, to image a substance/feature and to monitor the movement of an imaged substance/feature. The systems and methods can be adapted for a variety of applications at a wide range of scales and distances, from large scale, long range applications such as geophysical imaging/analysis, to the small scale such as material typecasting applications and small scale (including microscopic) imaging/analysis, including biological and medical imaging and diagnostic applications. The invention includes novel antenna assemblies and novel data processing techniques.

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*Fig. 1*

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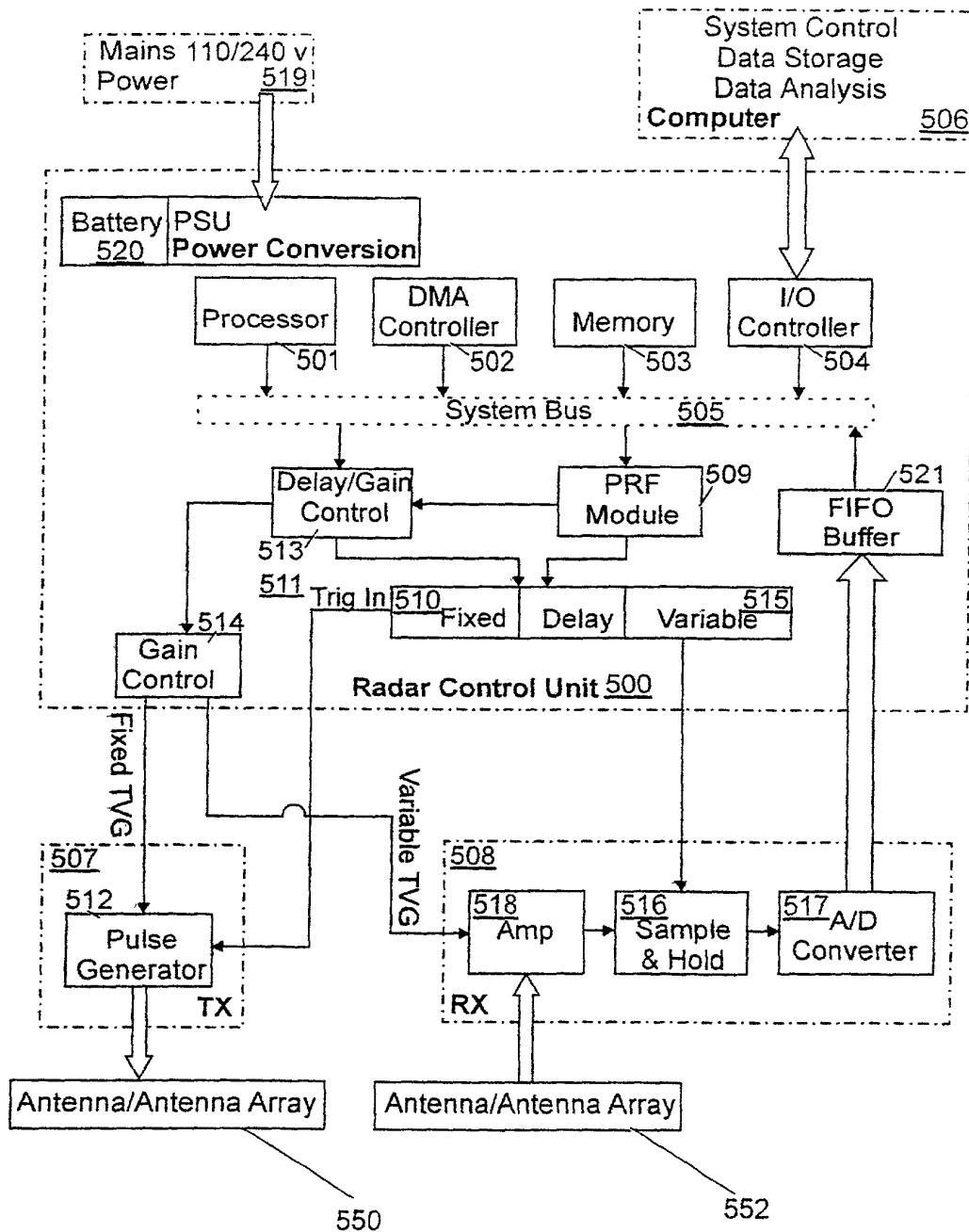


Fig. 2

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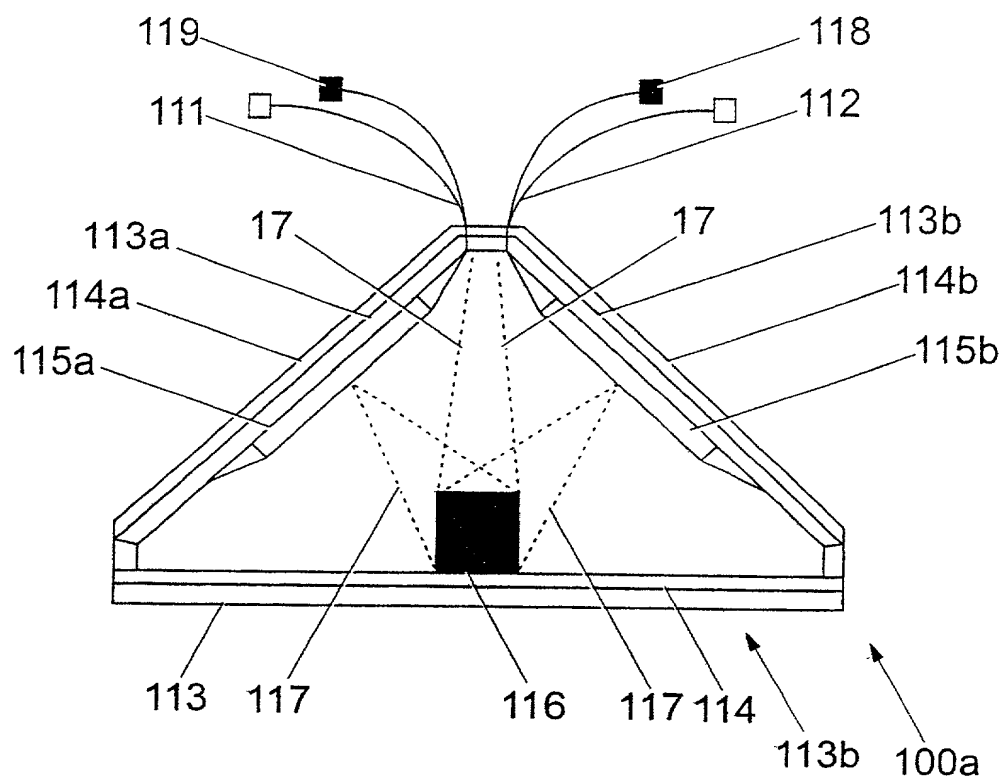


Fig. 3A

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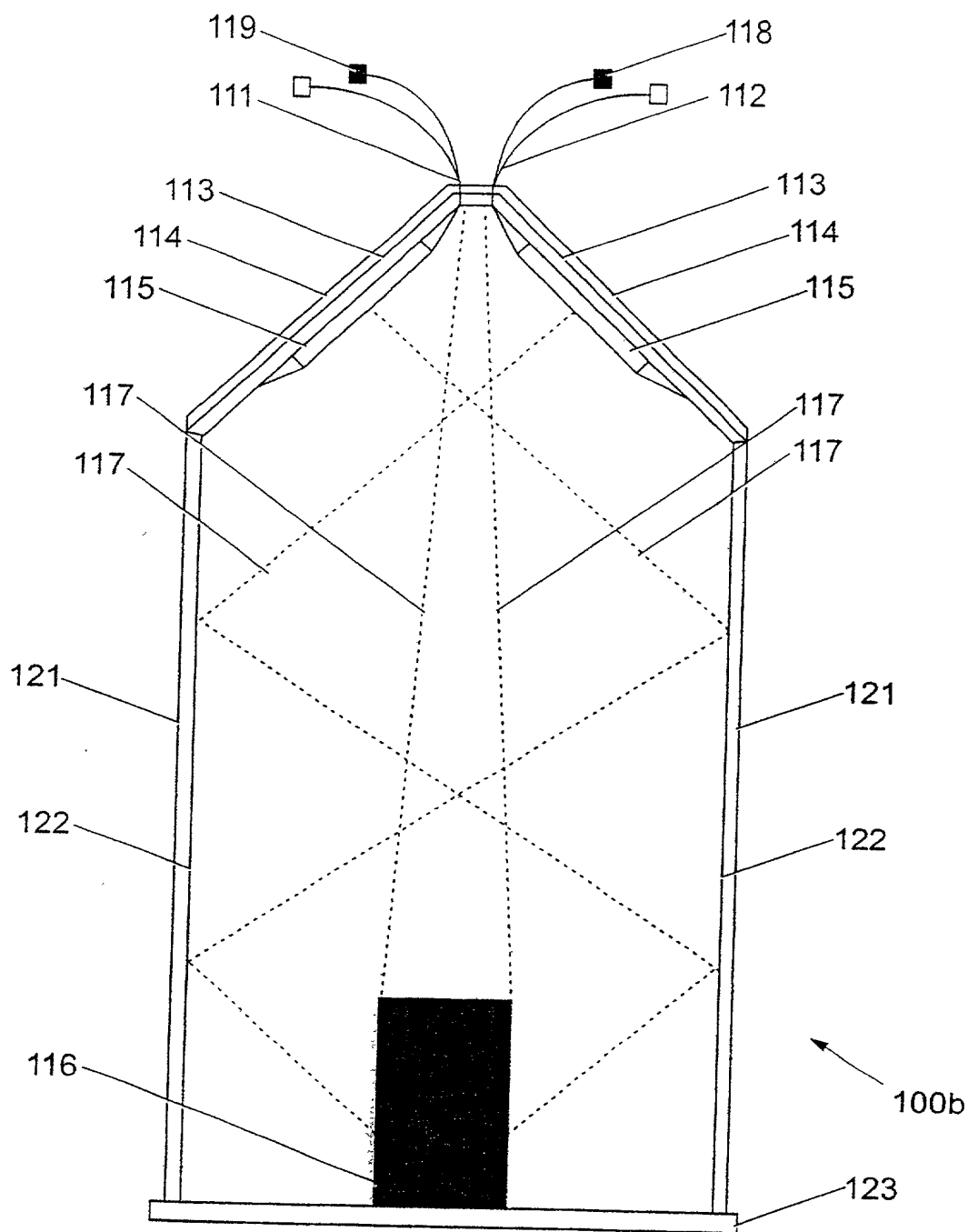


Fig. 3B

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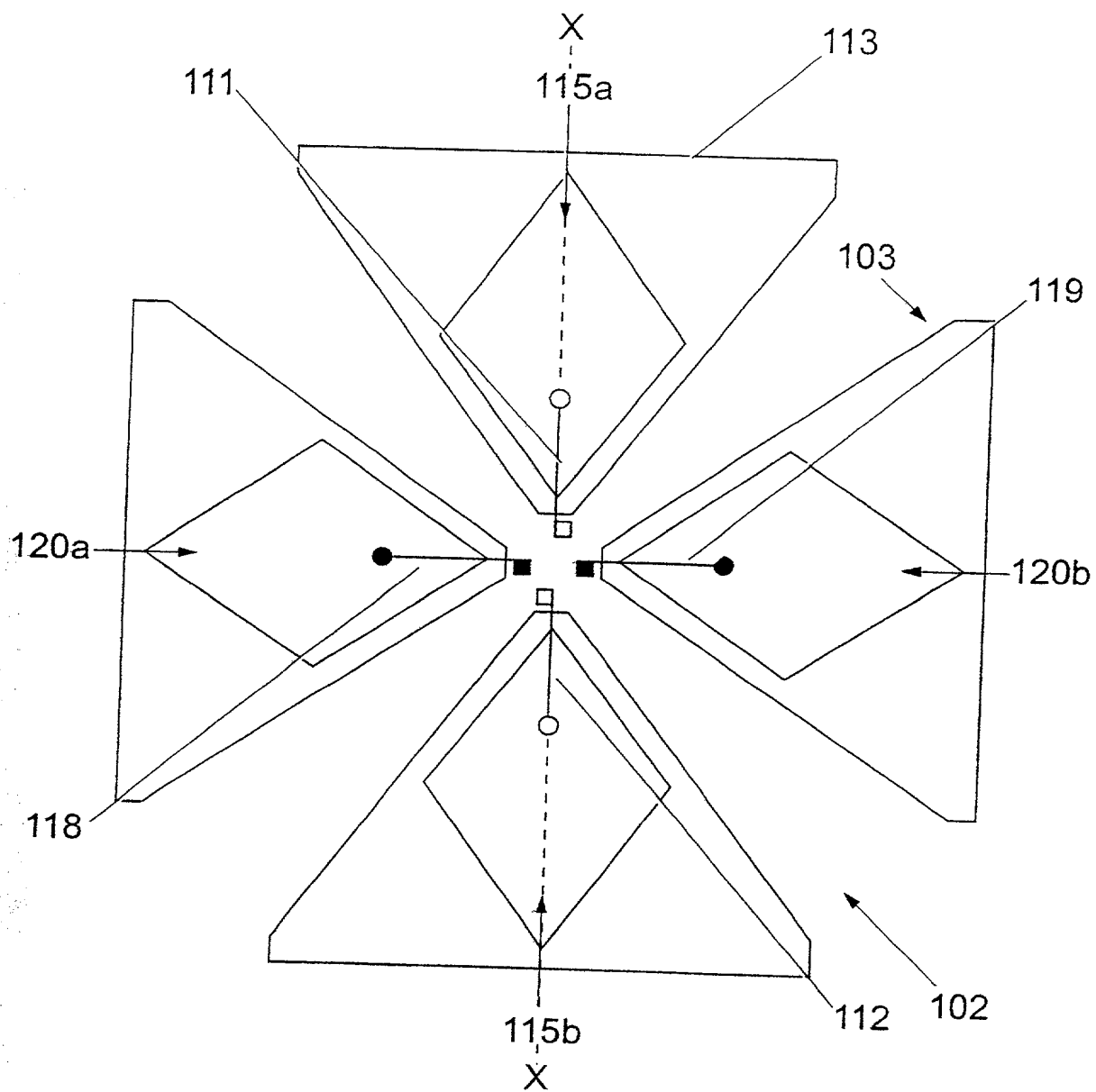


Fig. 4

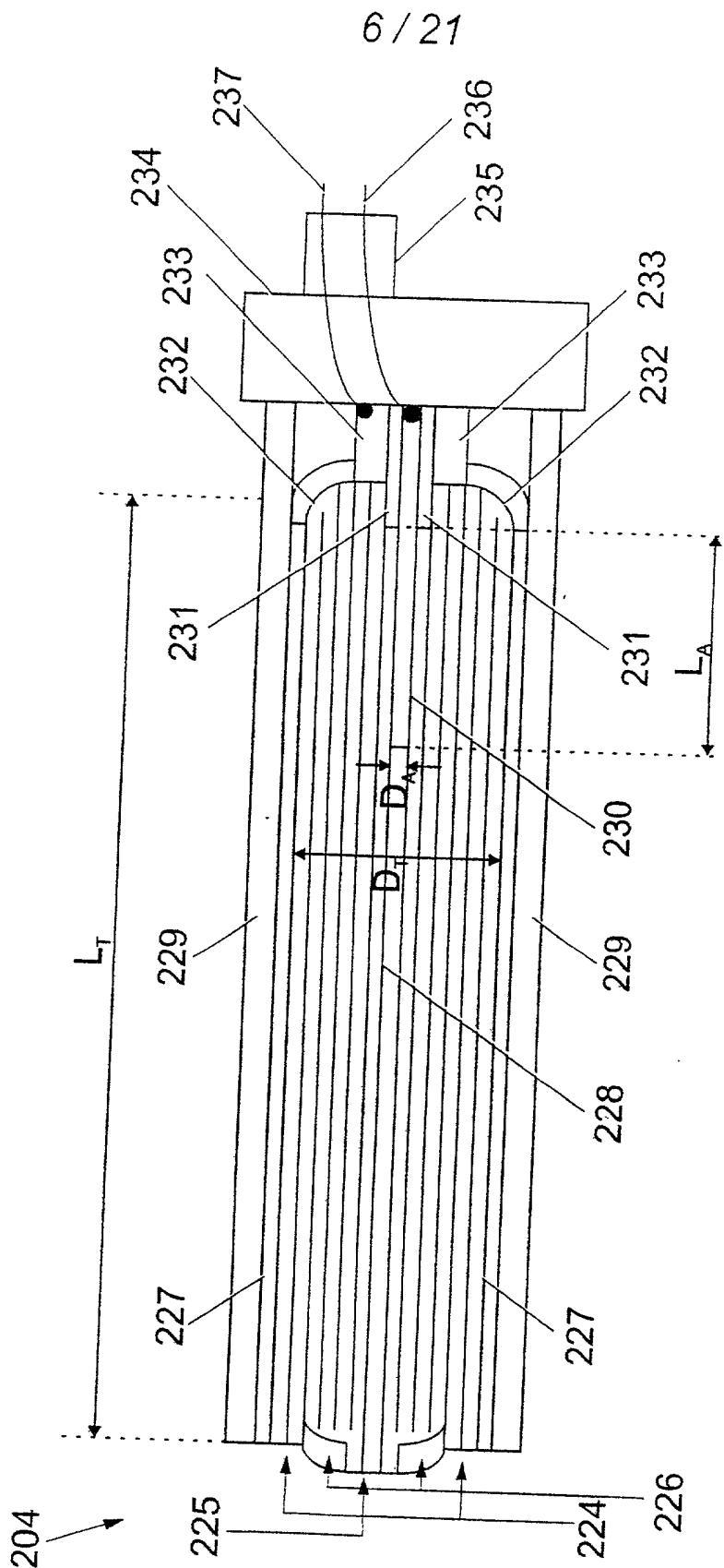


Fig. 5A

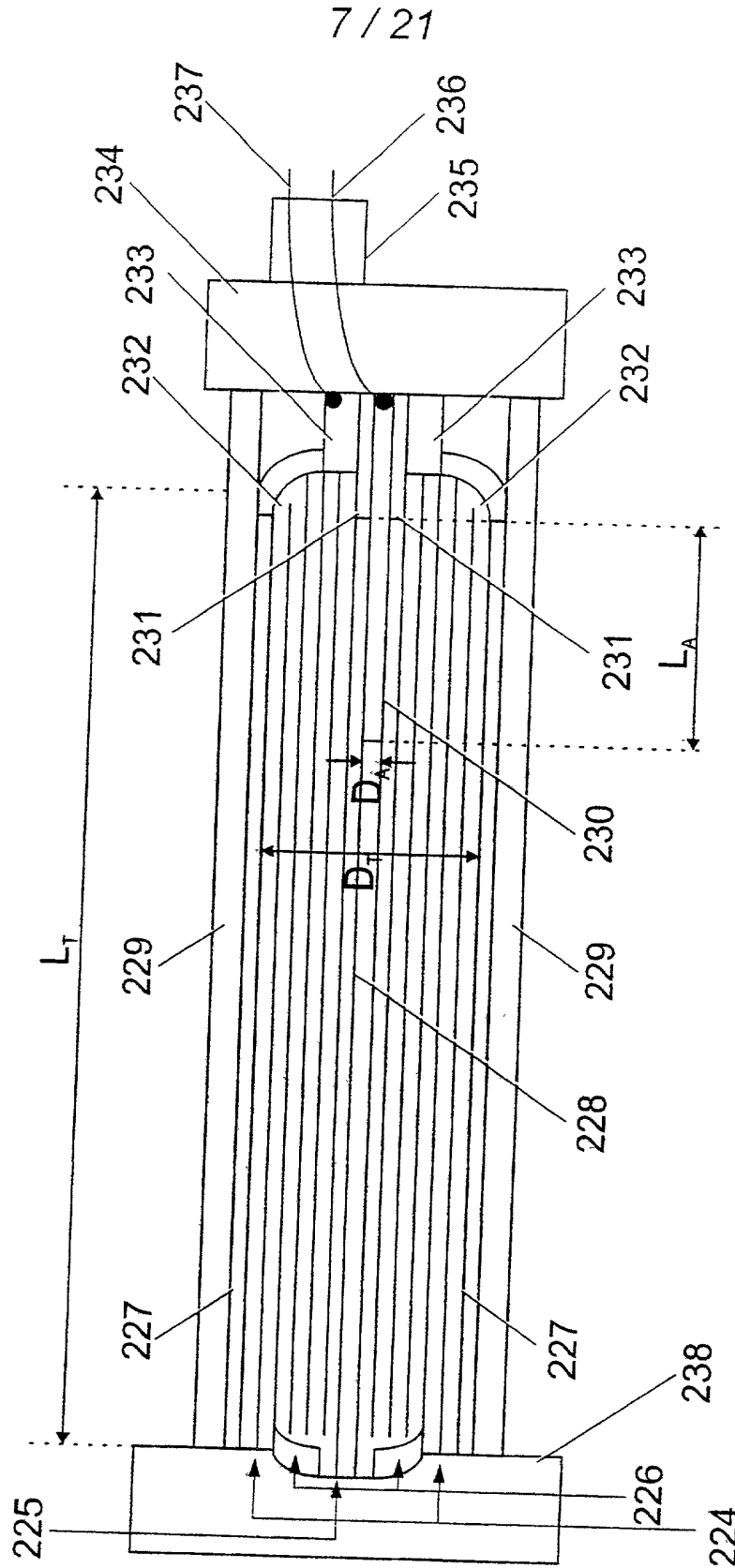


Fig. 5B

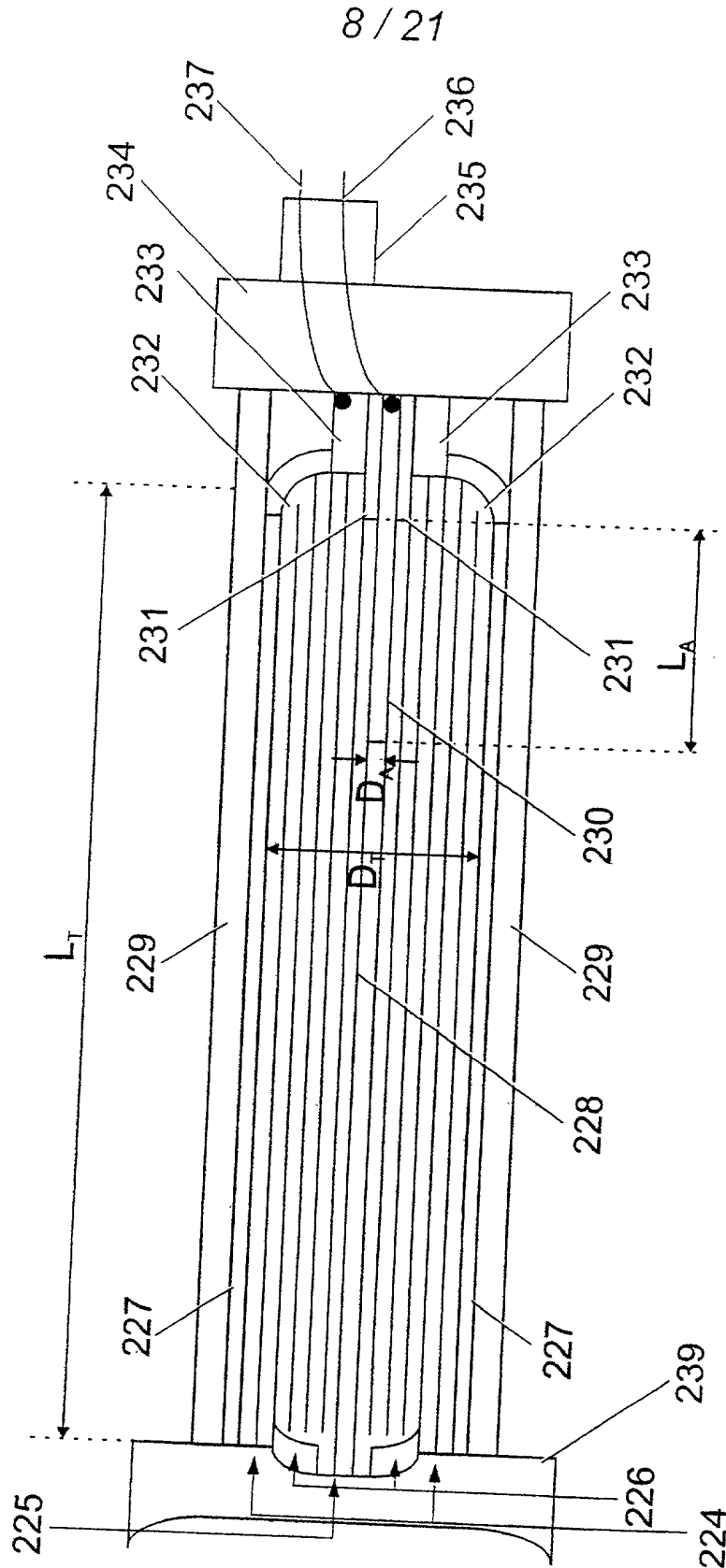


Fig. 5C

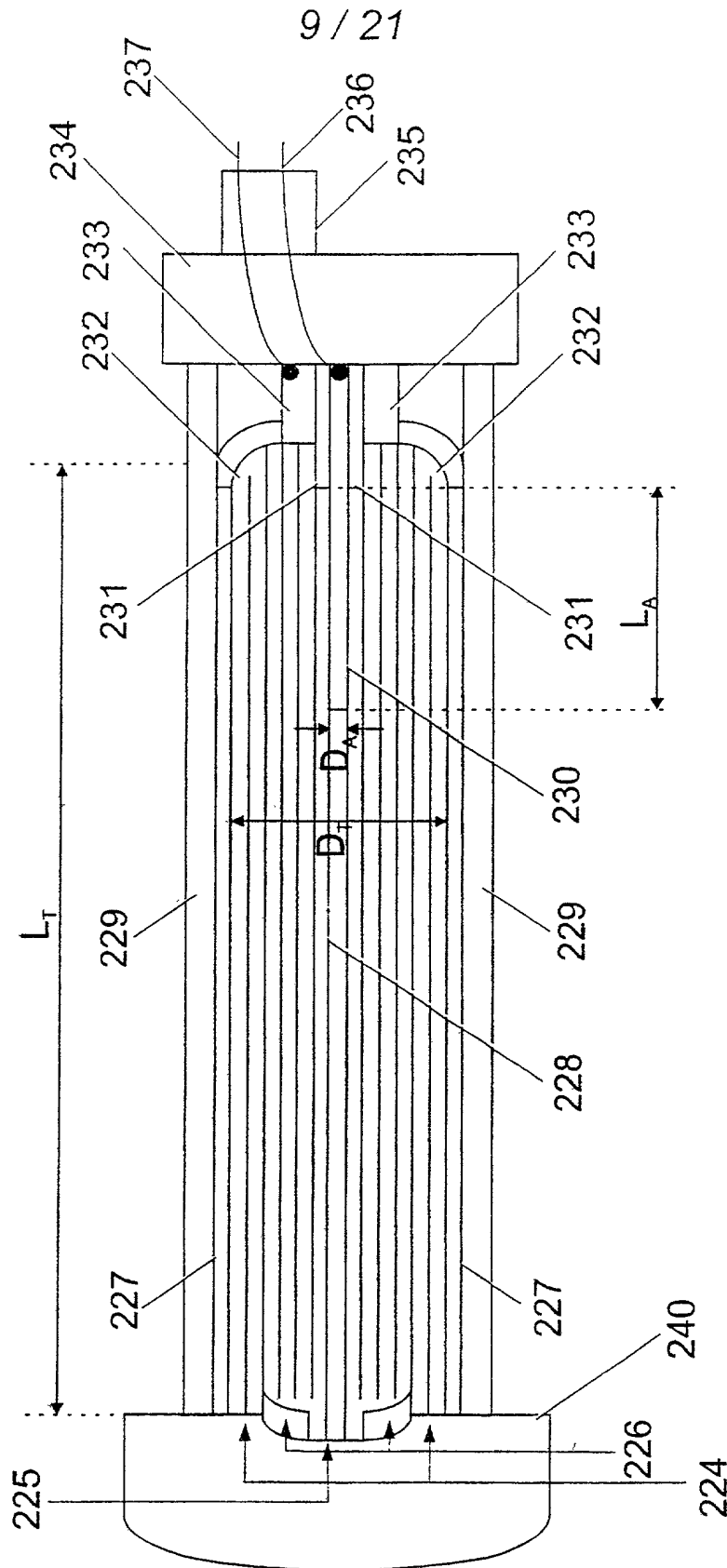


Fig. 5D

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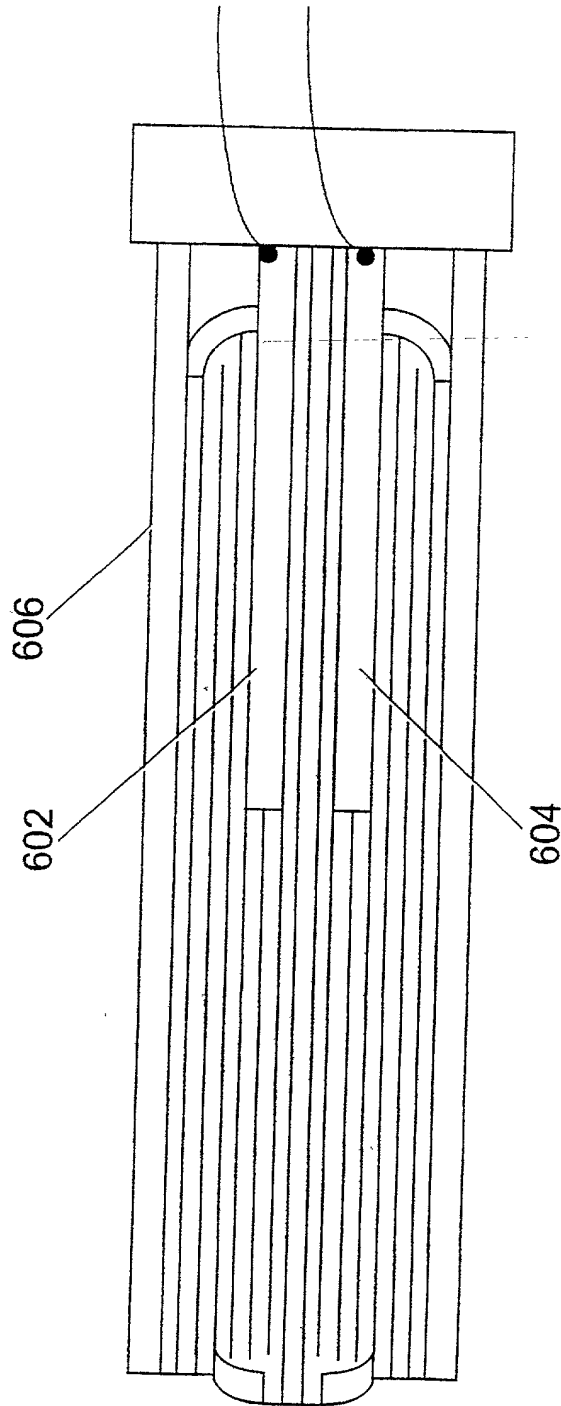
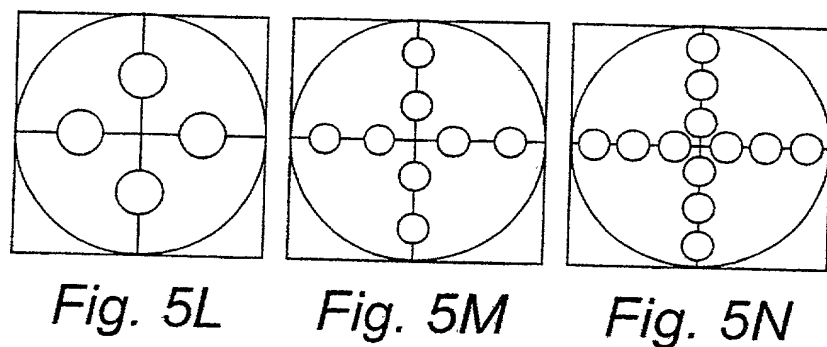
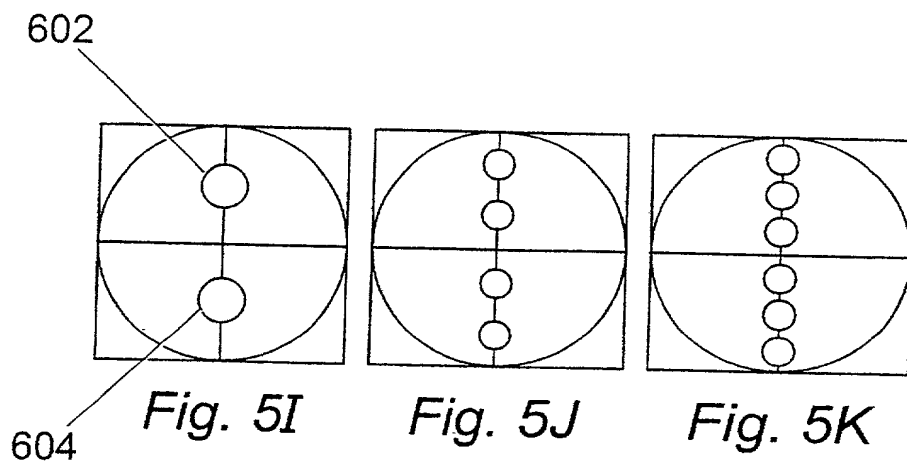
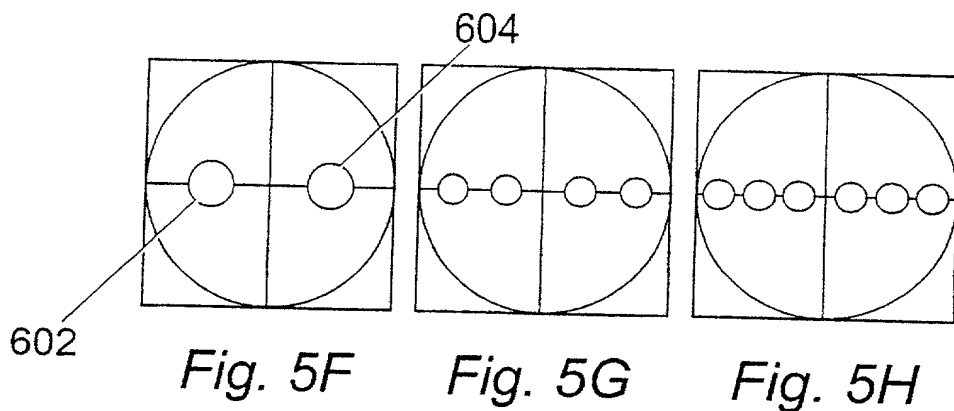


Fig. 5E

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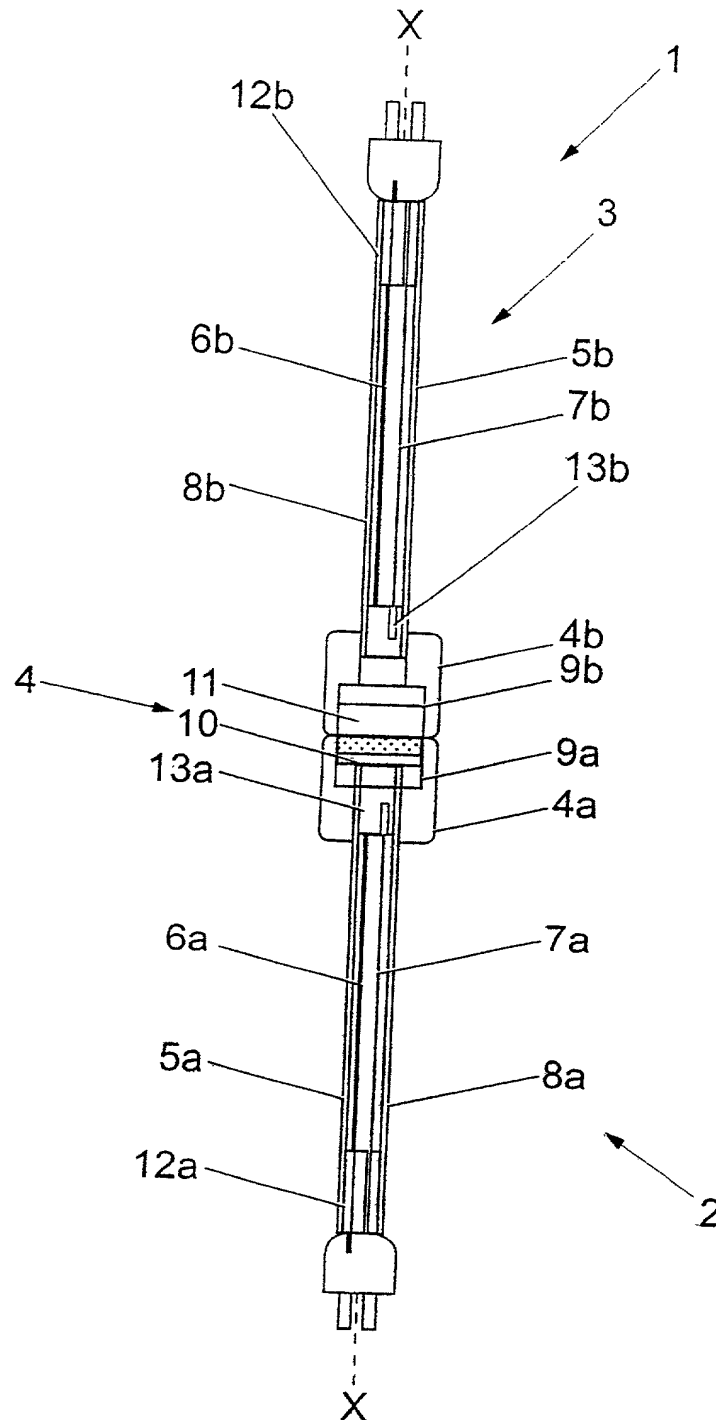


Fig. 6A

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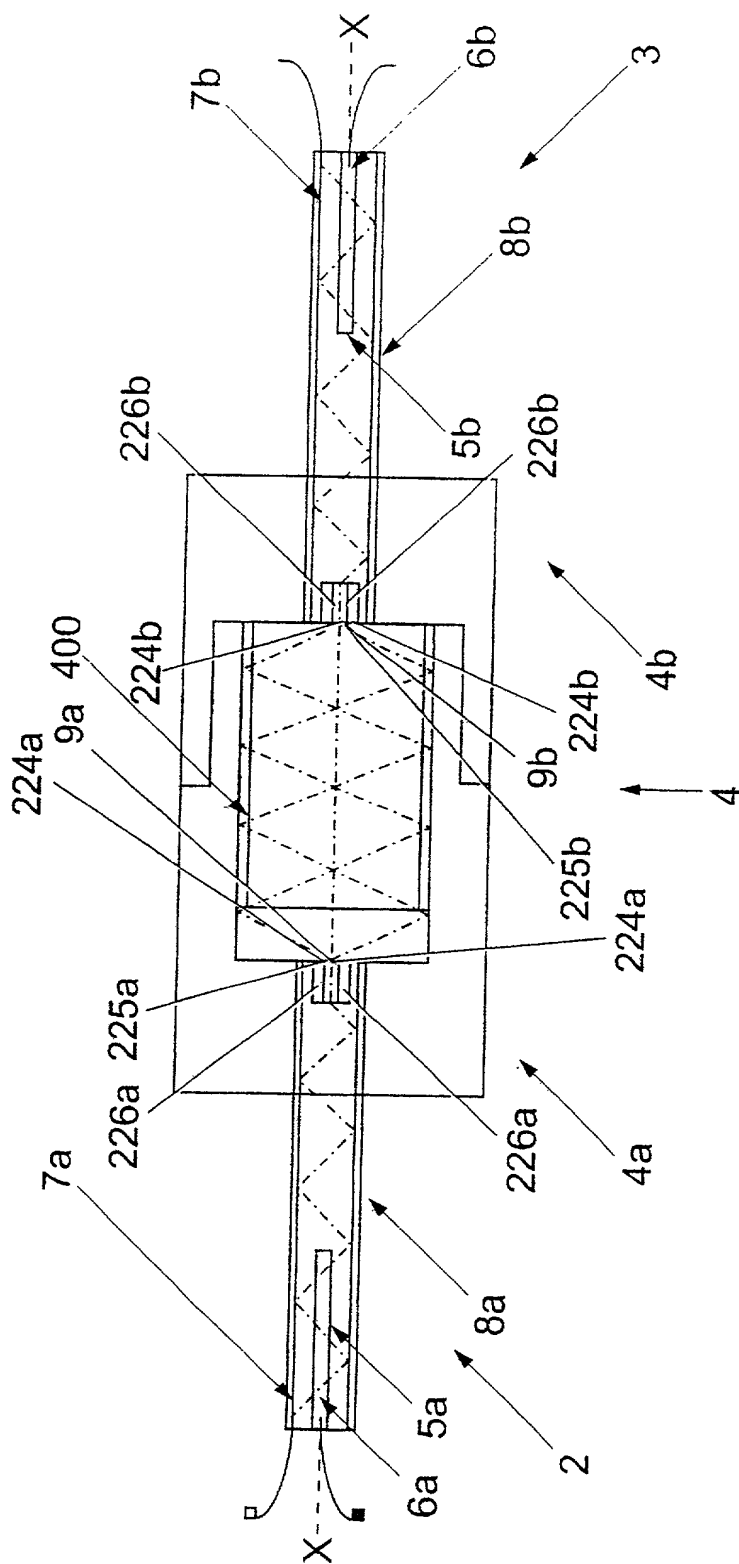


Fig. 6B

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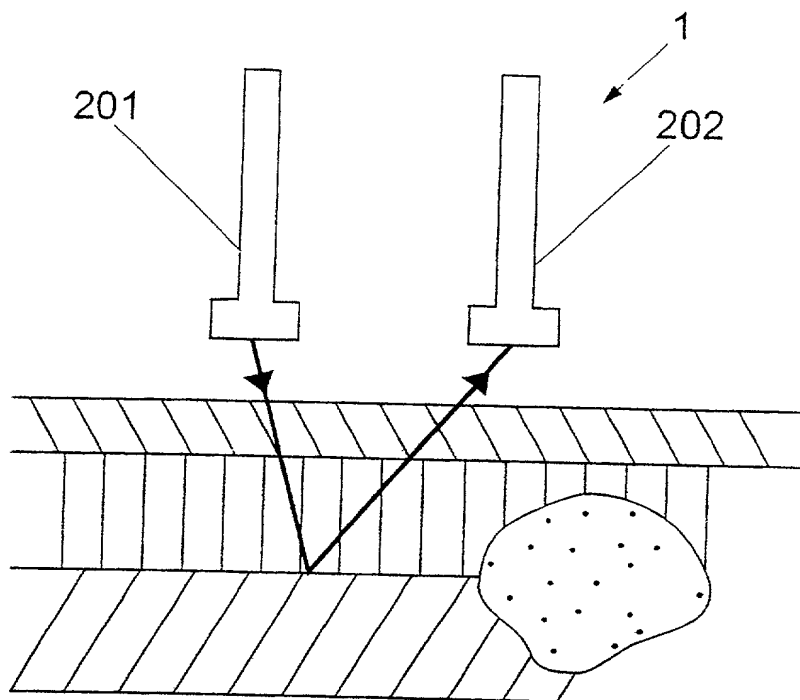


Fig. 7A

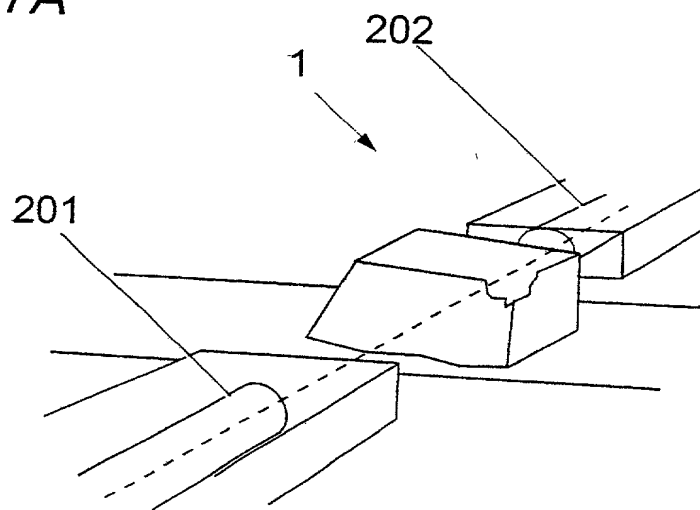


Fig. 7B

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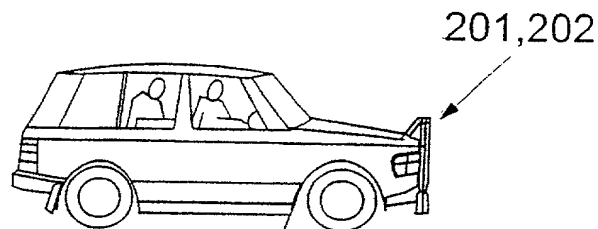
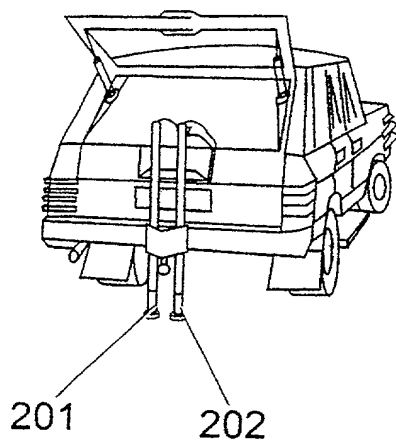


Fig. 8A

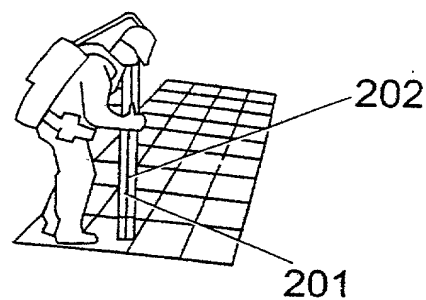
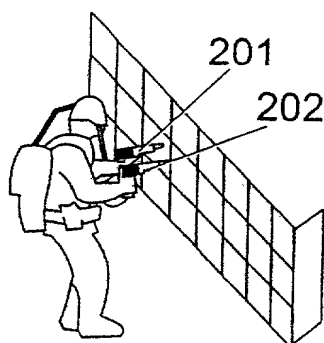


Fig. 8B

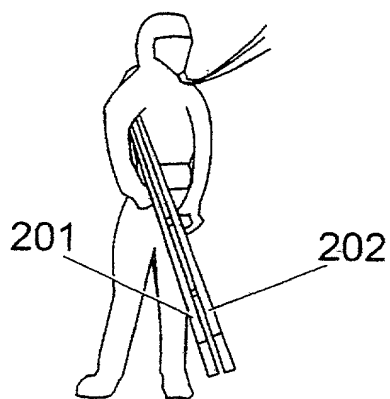


Fig. 8C

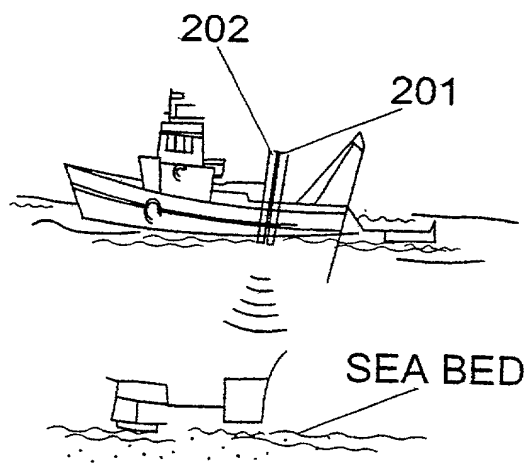


Fig. 8D

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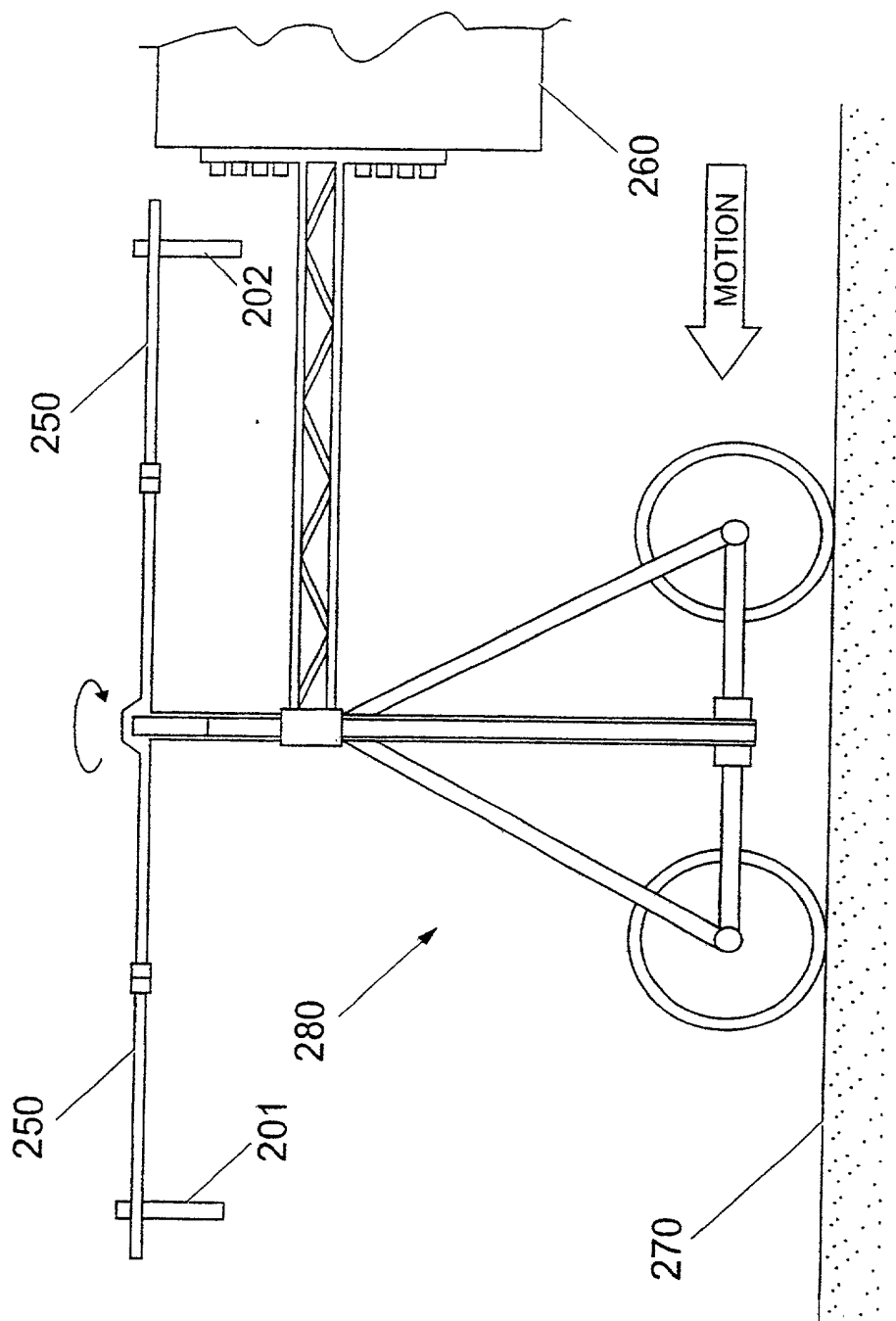


Fig. 9

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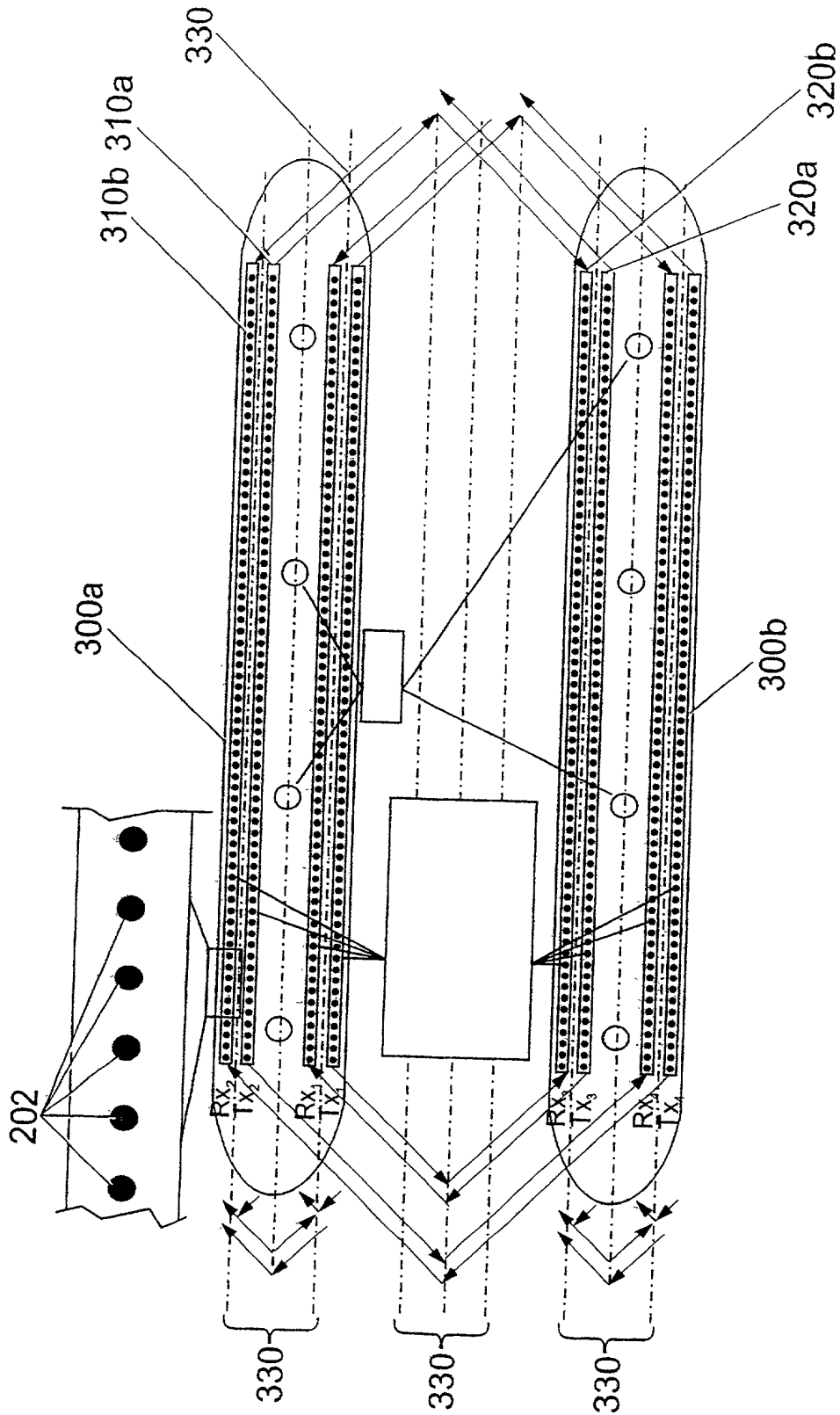


Fig. 10

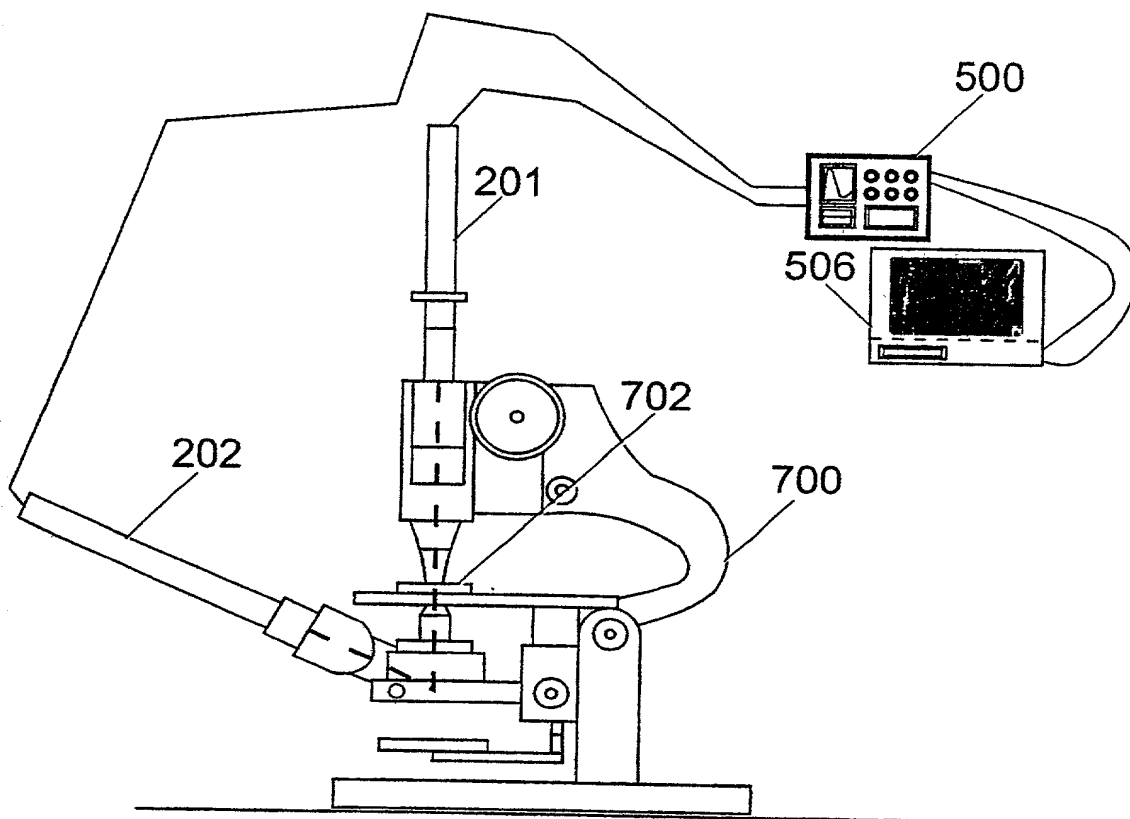


Fig. 11A

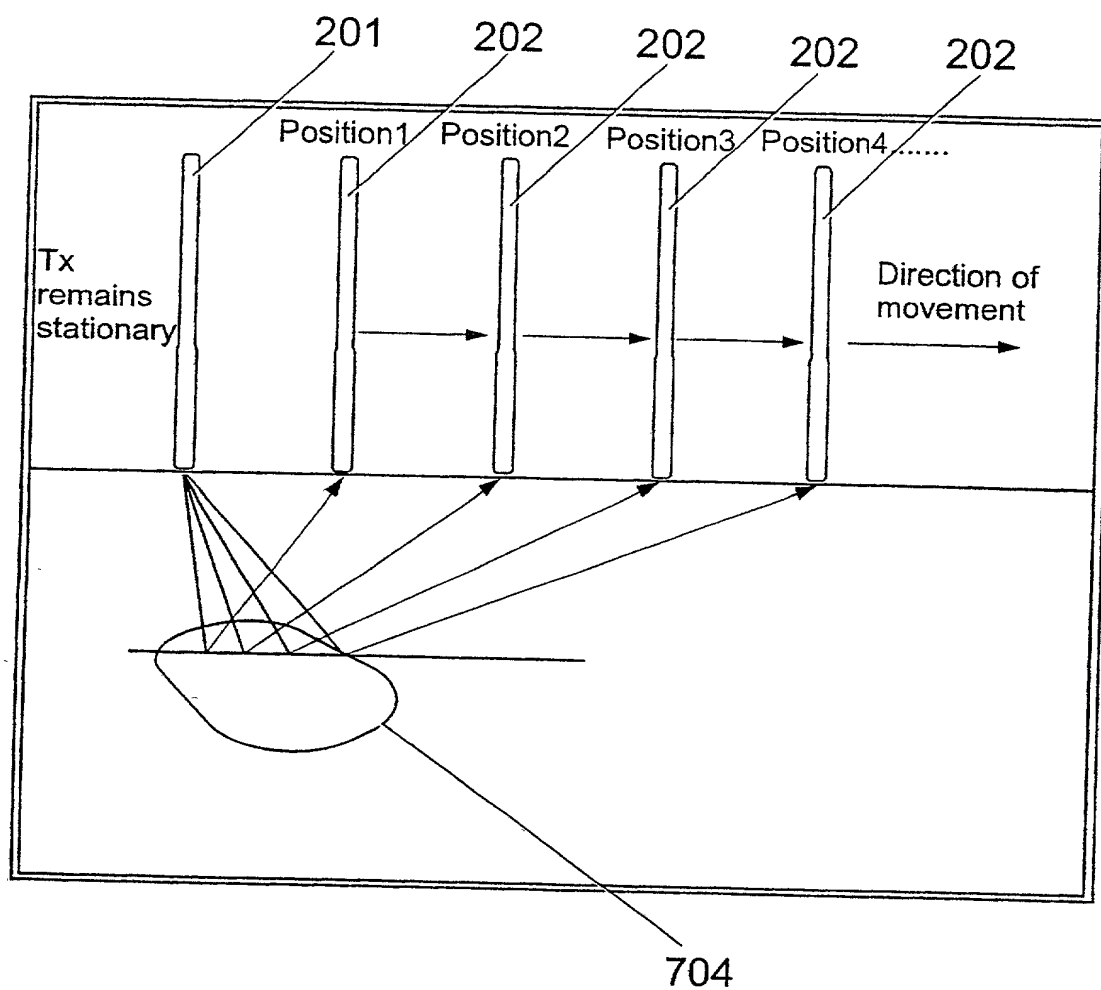


Fig. 11B

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MODE	Resolution Time (ps)	Resolution Space (m) (in salt water)	PRF (kHz)	Pw (ns)	TR (ns)	Fmax (MHz)	Fmin (MHz)	P _{tr}	ScanRate (traces/s)	1/SR (Sdelay)	T _s (ns)
A1	50	0.00167	100	0.1	2	10000	1000	40	2500	0.0004	0.05
A2	50	0.00167	100	0.1	5	10000	1000	100	1000	0.001	0.05
A3	100	0.00167	100	0.1	10	5000	500	100	1000	0.001	0.1
A4	250	0.00167	100	0.1	15	2000	200	60	1667	0.0006	0.25
A5	500	0.00167	100	0.1	25	1000	100	50	2000	0.0005	0.5
B1	250	0.01667	100	1	2000	2000	125	8000	12.5	0.08	0.25
B2	500	0.01667	100	1	4000	1000	62.5	8000	12.5	0.08	0.5
B3	625	0.01667	100	1	6000	800	50	9600	10.4	0.096	0.625
B4	1250	0.01667	50	1	8000	400	25	6400	7.8125	0.128	1.25
B5	2500	0.01667	25	1	10000	200	12.5	4000	6.25	0.16	2.5
C1	2500	0.16667	50	10	20000	200	12.5	8000	0.625	1.6	2.5
C2	5000	0.16667	25	10	40000	100	6.25	8000	0.3125	3.2	5
C3	10000	0.16667	12.5	10	80000	50	2.25	8000	0.15625	6.4	10
C4	40000	0.16667	6.25	10	160000	12.5	1	4000	0.15625	6.4	40
C5	62500	0.16667	3.125	10	250000	12.5	1	4000	0.078125	12.8	40

Fig. 12

Sampling Rate = $F_s = 2 \cdot F_{\max}$ Range for all generic types = $1/4 F_{\max} - 4 F_{\max}$ $P_{tr} = \text{Time Range} (TR) / \text{Sampling Time} (ts)$ Sampling Time = $T_s = 1/2 F_{\max}$, time occupied

by 1 pixel in the y-direction going down the trace

P_{tr} = number of pixels per trace
PRF = Pulse Repetition Frequency

Pw = Pulse Width

TR = Time Range

F_{max} = Maximum FrequencyF_{min} = Minimum Frequency

Resolution Time = time between pixels going down the trace

SR = Sampling Rate

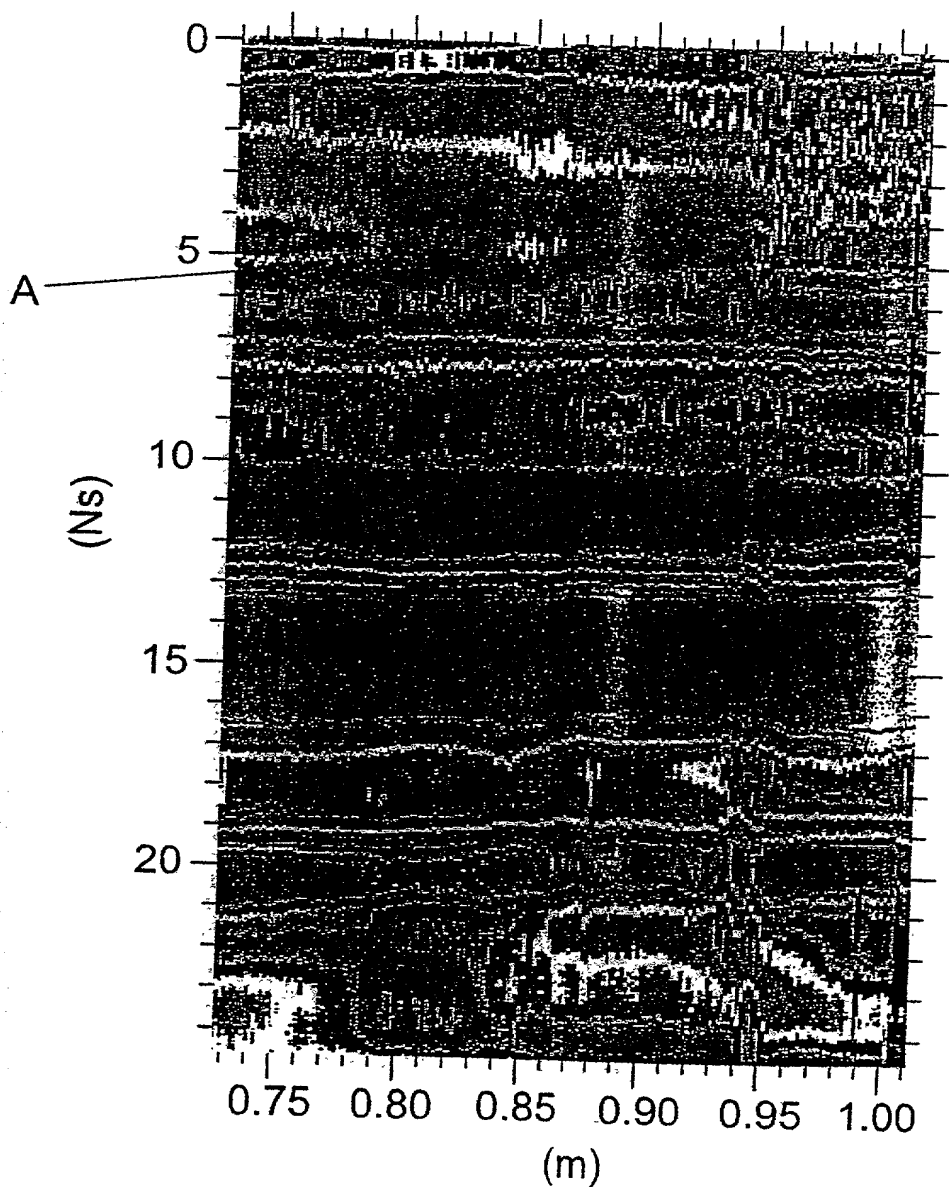


Fig. 13

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

"Radar Apparatus for Imaging and/or Spectrometric Analysis and Methods of Performing Imaging and/or Spectrometric Analysis of a Substance for Dimensional Measurement, Identification and Precision Radar Mapping"

the specification of which (check one)

☐ is attached hereto.

☒ was filed on September 7, 2000 as United States Application Serial No. _____ or PCT International Application No. PCT/GB00/03431 and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability in accordance with Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code §119(a)-(d) of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

PRIORITY FOREIGN APPLICATION(S)

<u>9921042.9</u>	<u>United Kingdom</u>	<u>07 September 1999</u>	Priority Claimed
(Number)	(Country)	(Day/month/year filed)	Yes [X] No []
<u>PCT/GB00/03431</u>	<u>PCT</u>	<u>07 September 2000</u>	Yes [X] No []
(Number)	(Country)	(Day/month/year filed)	

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

(Application Number) (Filing Date)

(Application Number) (Filing Date)

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56 which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.) (Filing Date) (Status)(patented,
pending, abandoned)

(Application Serial No.) (Filing Date) (Status)(patented,
pending, abandoned)

⑧ And I hereby appoint Arthur H. Seidel, Registration No. 15,979; Gregory J. Lavorgna, Registration No. 30,469; Daniel A. Monaco, Registration No. 30,480; Thomas J. Durling, Registration No. 31,349; John J. Marshall, Registration No. 29,671; Joseph R. DelMaster, Jr., Registration No. 38,123; Robert E. Cannuscio, Registration No. 36,469, and George A. Frank, Registration No. 26,708, my attorneys or agents with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith.

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and that all statements made on information and belief are believed to be true; and further that
these statements were made with the knowledge that willful false statements and the like so
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